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The military already recognizes the potential value of UAVs to perform tasks previously accomplished by manned aircraft. In addition to significantly lower costs in comparison with manned alternatives, unmanned aircraft can be tasked to fly missions deemed unduly risky for humans, both in an environmental sense as well as from the combat loss standpoint. UAV development is a serious, cost effective answer to the operational needs of the US military preparing for tomorrow's battlefield. UAVs are a key element within the concept of information dominance.

The objective of this issue of *The DTIC Review* is to review the capabilities, design and architecture of unmanned aerial vehicles common in military and commercial activities. Many challenges remain in UAV development if the United States is to continue to improve our performance of the intelligence, surveillance and reconnaissance mission and to fully exploit this technology in the 21st century.

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ERRATA

Document Two, *Unmanned Aerial Vehicles and Weapons of Mass Destruction: A Lethal Combination?*, AD A329050, is missing pages IV, VI, VIII, and 40. All the data appears to be present and the document was most likely misnumbered by the original author.

Document Three, *Medusa's Mirror: Stepping Forward to Look Back "Future UAV Design Implications from the 21st Century Battlefield"*, AD A339467, has duplicate abstracts in the front of the document, as provided by the author.

FOREWORD

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The editorial staff hope you find this effort of value and appreciate your comments.

Kurt N. Molholm
Administrator

TABLE OF CONTENTS

INTRODUCTION

Unmanned aerial vehicles commonly referred to as UAV's are defined as powered aerial vehicles sustained in flight by aerodynamic lift over most of their flight path and guided without an onboard crew. They may be expendable or recoverable and can fly autonomously or piloted remotely.[1] UAVs are a key element within the concept of information dominance. Historically the greatest use of UAVs have been in the areas of intelligence surveillance and reconnaissance. While UAVs play an increasing role in these mission areas, we are just beginning to understand the operational impact of multiple UAV operations and their importance to 21st century air power needs and future warfighters. As the US military adapts to a new set of realities and new ways of doing business, greater possibilities evolve for the employment of UAVs.

The military already recognizes the potential value of UAVs to perform tasks previously accomplished by manned aircraft. In addition to significantly lower costs in comparison with manned alternatives, unmanned aircraft can be tasked to fly missions deemed unduly risky for humans, both in an environmental sense as well as from the combat loss standpoint. UAV development is a serious, cost effective answer to the operational needs of the US military preparing for tomorrow's battlefield.

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The selected documents and bibliography are a representation of the information available on unmanned aerial vehicles from DTIC's extensive collection on this topic. Additional references, including electronic resources, can be found at the end of the volume. In-depth literature searches may be requested by contacting the Reference and Retrieval Services Branch at the Defense Technical Information Center:
(703) 767-8274/DSN 427-8274; FAX (703) 767-9070; E-mail bibs@dtic.mil

[1] Armitage, Air Chief Marshal Sir Michael. *Unmanned Aircraft.* London: Brassey's Defence Publishers, 1988.

DOCUMENT 1

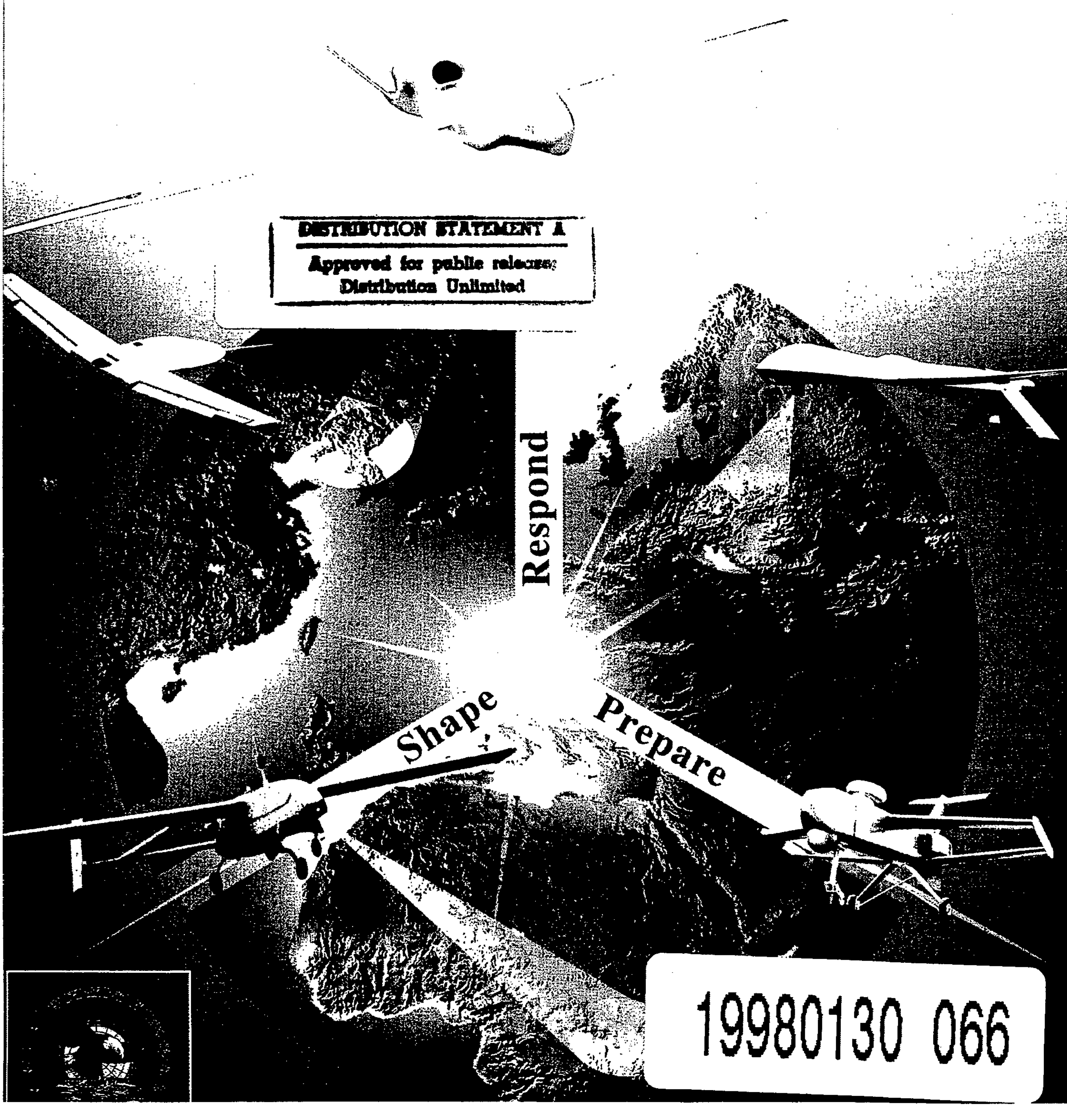
UAV Annual Report, FY 1997

AD-A336710

1997

Office of the Under Secretary of Defense
(Acquisition & Technology) (OUSD(A&T))
Defense Airborne Reconnaissance Office (DARO)
Washington, DC 20301-3160

UAV Annual Report FY 1997



Airborne reconnaissance is enduring, but it is not unchanging. As we look to the future, we see our mix of airborne reconnaissance assets evolving in response to new technologies as well as joint strategies, doctrine, and a more diverse threat. In this UAV Annual Report, our third, we see unmanned aerial vehicles playing an ever-increasing role, not only in the intelligence, surveillance and reconnaissance (ISR) world, but in other mission areas as well. The U.S. military faces a challenging future in an era of dynamic change, constrained resources, potential new roles, and rapid technological advancement. These factors require innovative thinking and new ways to shape change. UAVs will help us shape this change. They represent both a revolution in military affairs and a revolution in business affairs.

Joint Vision 2010 (JV 2010) is built on the premise that modern and emerging technologies — particularly information-specific advances — should make a new level of joint and coalition capability possible. Underlying these technological innovations is information superiority, the ability to collect, process and disseminate an uninterrupted flow of information while exploiting or denying an adversary's ability to do the same. We can achieve full spectrum dominance through:

1. Dominant Maneuver; *2. Precision Engagement;*
3. Full-Dimensional Protection; and *4. Focused Logistics.*

> ***"There always comes a moment in time when a door opens and lets the future in."***
>
> ***Graham Green***

The capacity to dominate any adversary and control any situation in any operation will be the key capability we ask of our armed forces in the 21st century. UAVs will provide a sustained, responsive, accurate picture of the battlefield.

In addition to JV 2010, our operational concept for the future, the National Security Strategy for a New Century stresses the "imperative of engagement." Many aspects of our strategy are focused on shaping the international environment to deter or prevent threats. A second element of this integrated approach is the requirement to maintain an ability to respond across the full spectrum of potential crises, up to and including fighting and winning major theater wars. Finally, we must prepare today to meet the challenges of tomorrow's uncertain future.

As you can see on the cover of this year's report, we expect to use our growing UAV capability to support our national strategy, to include being "on call" to respond to transnational threats. Our tactical and endurance UAVs continue to make significant progress and will complement both our manned systems and our space sensors. We can take great satisfaction from the following accomplishments:

- Predator, *the Defense Department's first Advanced Concept Technology Demonstration Program (ACTD), was approved for production and a block upgrade program. Our other ACTDs, the* Outrider *Tactical UAV and the* Global Hawk *and* DarkStar *High Altitude Endurance (HAE) UAVs, experienced delays but are on track for 1998.* Outrider *has flown successfully with its new UEL engine.*
- Pioneer *continues its operational service and passed the 15,000 flight-hour mark this past July. Detachments both continue their shipborne deployments and support the test, evaluation and demonstration of UAV subsystems and payloads. Readiness has been increased to about 70 percent.*
- *The Tactical Control System (TCS), which will provide an interoperable system to enable multiple host systems to interface eventually with all UAVs, has been demonstrated successfully. So has* Outrider's *ground station.* Predator's *ground station will be procured in a smaller, repackaged version for easier transport and use in the field.*
- *Among subsystems, the UAV Common Automated Recovery System (UCARS) was*

acquisition by both tactical UAVs and Predator. *As for the HAE UAVs,* DarkStar's *electro-optical (EO) and synthetic aperture radar (SAR) sensors and* Global Hawk's *radar sensor have been flown successfully on testbed aircraft.*

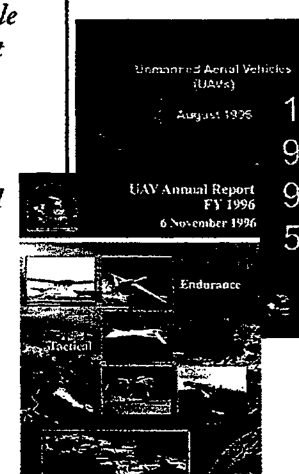
- *The Air Force has activated both its UAV Battlelab (at Eglin AFB, FL) and the 15th Reconnaissance Squadron (RS) (like the 11th RS, near Nellis AFB, NV). The UAV Battlelab, like the other Services' battle labs, is exploring UAV contributions to both Service and joint missions. The 15th RS was established two years early to be fully prepared for* Predator's *fielding in quantity.*
- *The Joint Requirements Oversight Council's UAV Special Studies Group (JROC UAV SSG) has continued its prioritization of payloads by mission, in conjunction with the Services and operational Commanders-in-Chief (CINCs), for* Outrider, Predator, Global Hawk, *and* DarkStar. *This will rationalize UAV payload requirements across systems and missions, as a warfighter's guide for acquisition planning.*
- *The Command, Control, Communications, Computers, and Intelligence, Surveillance and Reconnaissance (C4ISR) Joint Warfighting Capability Assessment (JWCA) process has developed UAV concepts and identified UAV contributions to JV 2010. In further support, the DARO Architecture Development Team (DADT) has developed an Objective Architecture for the year 2010, together with a force migration roadmap and investment strategy to achieve it. Our Communications Systems Analysis provided air and space communications needs to support airborne reconnaissance and complement space-based intelligence systems.*
- *Finally, resolution of several program and management issues with Congress and within the Department strengthened our overall approach to UAV acquisition while reaffirming the importance of a family of UAV capabilities to meet the needs of 21st century warfighters.*

In summary, FY 1997 has been a transition year. The UAV community has persevered both in meeting acquisition challenges and in integrating projected UAV capabilities into military operations wherever useful. Our challenge for the near future will be to prove and build enough UAV systems to meet this expanding demand while ensuring their operational fit into current force structures and C4ISR functions. Working together, we have the opportunity to create a safer, more prosperous tomorrow for ourselves and our allies. I thank you for your continuing support, and look forward to the challenges of 1998.

Maj Gen Kenneth R. Israel, USAF
Director, Defense Airborne Reconnaissance Office

"You can take the example of [retired Chief of Staff] General Fogleman's vision to 'find, fix, target, track and engage anything of significance on the face of the earth' as we enter the next decade... Some of that you will do from airborne platforms, some of it from space platforms and some of it will migrate from one to the other. Some of it will always be best done with a combination of air and space."

Gen John Jumper, USAF
27 Oct 97
(Nominated for COMUSAFE)



DARO's World Wide Web site: http://www.acq.osd.mil/daro/

UAV Program Resource Summary

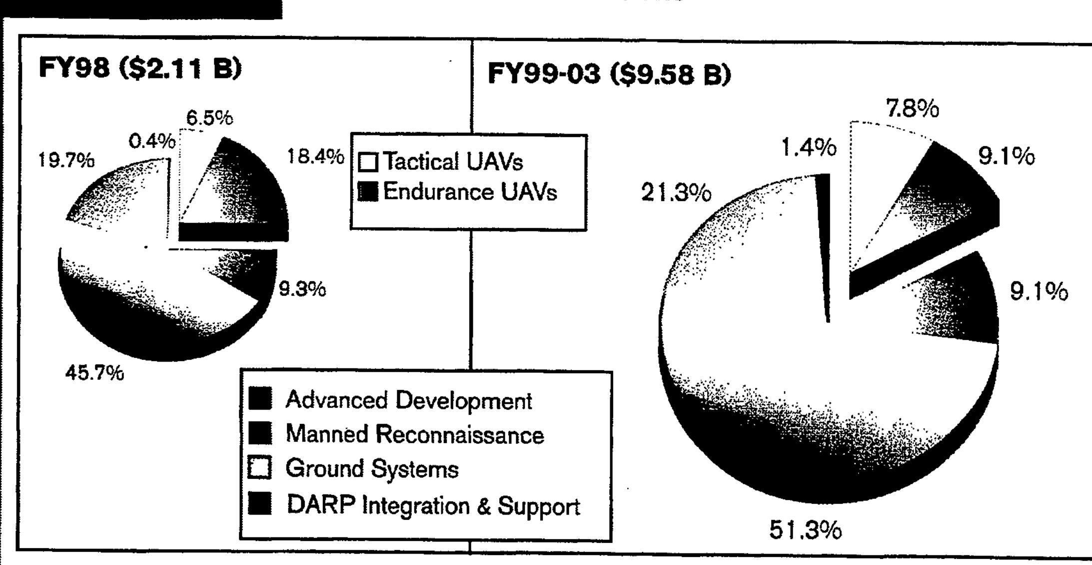
Tactical UAVs

- ❒ ***Pioneer*:** Nine systems operational with Navy and Marine Corps. Continual contingency deployments, test support.
- ❒ ***Hunter*:** Seven systems acquired. Army is operating one system for CONOPS development and training; other assets support tests and demonstrations.
- ❒ ***Outrider*:** Six systems planned for the Tactical UAV (TUAV) ACTD for Army, Marine Corps, and Navy. First flight occurred in Mar 97, followed by subsystem validation.

Endurance UAVs

- ❒ ***Predator*:** DoD's first ACTD; 12 systems now in acquisition. Existing assets in operation by the Air Force in Bosnia.
- ❒ ***Global Hawk*:** Five UAVs planned for HAE ACTD as a high-altitude, wide-area, long-dwell surveillance platform. Roll-out in Feb 97, taxied in Oct 97.
- ❒ ***DarkStar*:** Four UAVs planned for HAE ACTD as a high-altitude stealth UAV for wide-area surveillance of highly defended areas. Redesigned after AV #1 crash in Apr 96; AV #2 plans to taxi in Dec 97.

DARP Resource Allocations

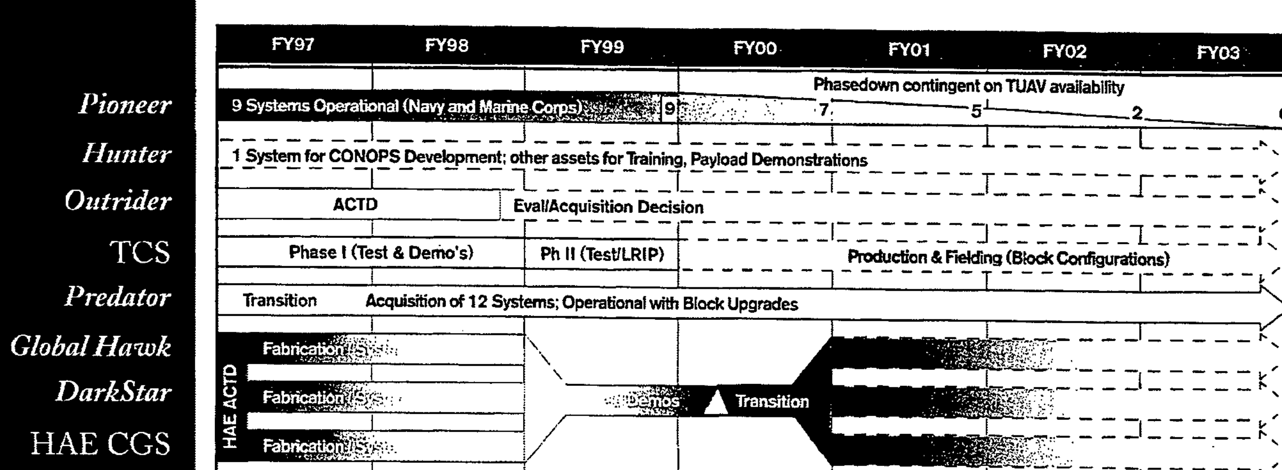


The Defense Airborne Reconnaissance Program (DARP) budgets about $2 billion per year for investment (RDT&E and Procurement).

UAV investment comprises 25% of the FY 1998 DARP budget, and 17% of the Future Years Defense Program (FYDP) in the out-years. (Production resources for *Outrider* and HAE UAVs are projected pending post-ACTD DoD procurement decisions).

Integrated UAV Schedule

Potential UAV and ground station program schedules are projected for the FYDP period.



Congressional Actions

Enactment of the FY 1998 Budget

Several Congressional committees with oversight over airborne reconnaissance addressed many UAV-related issues during the Authorization and Appropriations processes. The approved FY 1998 UAV budgets are tabulated below, with specific issues discussed in the numbered notes that follow.

Program / Item	Request [a]	Approp'n [b]	Remarks [c]	¶
Tactical UAV *(Outrider)*	$ 83.3	$ 45.0	Funding for ACTD without LRIP; funds transferred to Army	1
Common Systems Development (CSD)	4.2	0.0	HFE development funding (for TUAV) eliminated	2
Tactical Control System (TCS)	34.5	42.5	$8.0M added to support TCS for *Predator*	3
Vertical Takeoff and Landing (VTOL)	0.0	8.0	Plus-up to demonstrate advanced VTOL technologies	4
Multifunction Self-Aligned Gate (MSAG)	0.0	4.0	Funded (in the TCS line) to continue MSAG development	
Hunter Operations & Maintenance (O&M)	2.2	12.0	Plus-up to fund operation of existing *Hunter* systems	
Pioneer	4.0	7.0	Plus-up to support UCARS "throughout DoD"	
Pioneer	42.7	42.7	Fully funded	
Predator RDT&E	15.0	15.0	Funds transferred from Defense-wide to Air Force RDT&E	
Predator Procurement (UAVs & spares)	116.5	141.5	Fully funded procurement, plus $25.0M for additional spares	
Global Hawk	96.0	96.0	Fully funded *(Global Hawk* SIGINT not funded)	5
DarkStar	54.6	54.6	Fully funded	6
HAE Common Ground Segment (CGS)	51.1	42.1	$9.0M reduction, but not to be applied to the two HAE CGS	7

[a] President's Budget Request. [b] Appropriations prior to undistributed reductions and other adjustments. [c] All dollars in millions.

Notes on Congressional Program/Budget Actions

1. Provides $45 million for "the continued development, testing and evaluation of *Outrider*." (Also rescinded $20 million of FY 1997 funding.) The Army Secretary is to provide an acquisition strategy to the Appropriations Committees after user testing and evaluation are complete (see p. 27).
2. CSD not funded for FY 1998. Funding for heavy fuel engine development denied. Other common support programs funded separately: MSAG in the TCS line, and other activities under DARO's Advanced Technologies line.
3. Funds added to the TCS line to procure *Predator* assets for TCS integration.
4. Funds added to continue VTOL UAV demonstrations and to begin an advanced UAV technology program (that should include a stopped-rotor, high-speed, reaction-driven concept) (see p. 11).
5. HAE UAV ACTD platforms were fully funded. A separate initiative to develop a SIGINT payload for *Global Hawk* was denied.
6. Per request, DoD will conduct a study of Moving Target Indication (MTI) on *DarkStar*.
7. A $9 million reduction was directed to other items in the HAE CGS line, as prior-year funds "are available for continued testing" of the HAE CGS itself.

Additional Budget Impacts

An additional, undistributed FY 1998 budget reduction will further affect the numbers above and in the program description pages that follow. Allocations of this reduction are still being determined at press time.

Summary of FY 1998 Budget Actions

While the redirection of the Tactical UAV program line involves both funding and program changes, many of which parallel current DoD determinations, the Congress has continued its overall support for UAVs as systems that will play increasingly significant roles in military operations of the future. Generally sustained funding for FY 1998 programs attests to the Congress's continued interest in, and encouragement of, UAVs' expanding utility in pursuit of our national goals.

Predators Over Bosnia

Deployments to Europe to support joint and combined operations in the Balkans were the major UAV "success story" of last year. This success story continues. *Predator's* second deployment began in March 1996 and, though originally scheduled to end in February 1997, has been extended through February 1998. Meanwhile, *Pioneer's* land-based Bosnia deployment ended in October 1996, while naval deployments continue to the Adriatic and Mediterranean Seas.

Predator System Evolution

The configuration of *Predators* flying over Bosnia includes:

- EO/IR and synthetic aperture radar (SAR) imagery sensors;
- C-band and Ku-band SATCOM on-board links (a UHF SATCOM link is being removed); and
- Ice-mitigation features.

These capabilities reduce, but do not fully correct, *Predator's* vulnerability to in-flight icing. A "weeping wing" de-icing feature, which lightly sprays the front and upper wing surface with antifreeze, will finish testing in December 1997 and become part of the baseline configuration with subsequent retrofit into all existing systems (see p. 31).

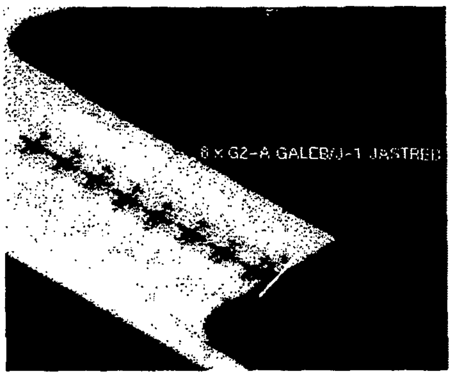
Predator's Operational Utility

Mission	Objective
Surveillance and Monitoring	Humanitarian Assistance
Target Location	NATO Troop Protection
Reconnaissance	Pre- and Post-Strike Intelligence
Battle Damage Assessment (BDA)	Dayton Peace Accord Enforcement
	Peace-keeping Support

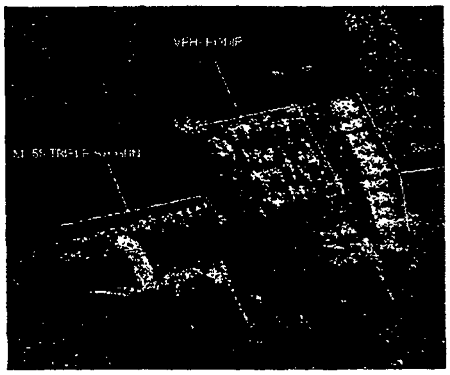
Predator's primary current missions are shown at left. The system generates critical and timely live imagery and imagery-derived intelligence for operational commanders and coalition forces. Support has been provided on a near-daily basis, often when other collection sources were not available. Recent examples of Bosnia imagery are shown below.

Bosnia Imagery

EO



IR



SAR

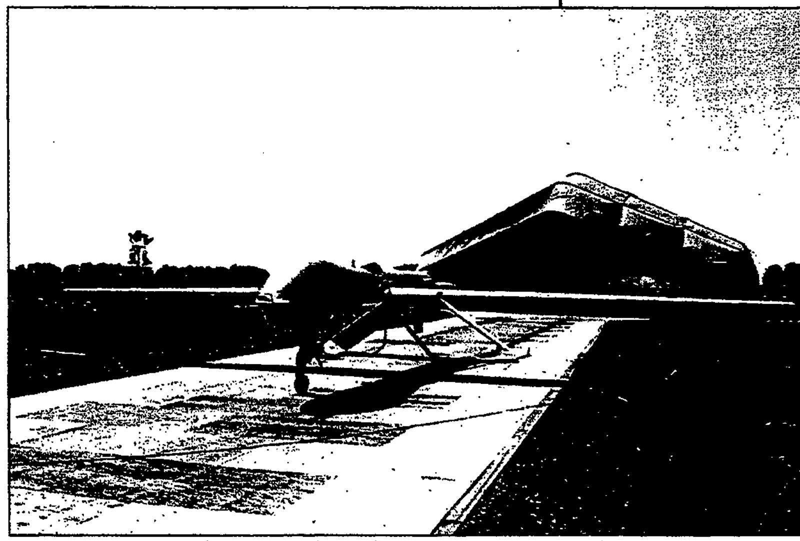
"The guys [at the Combined Air Operations Center] in Vicenza are dependent on UAVs. We need to make them work. We rely on them more than I thought."

Lt Gen Kenneth E. Eickmann, USAF Commander, Aeronautical Systems Center 24 Oct 97

Field Operations

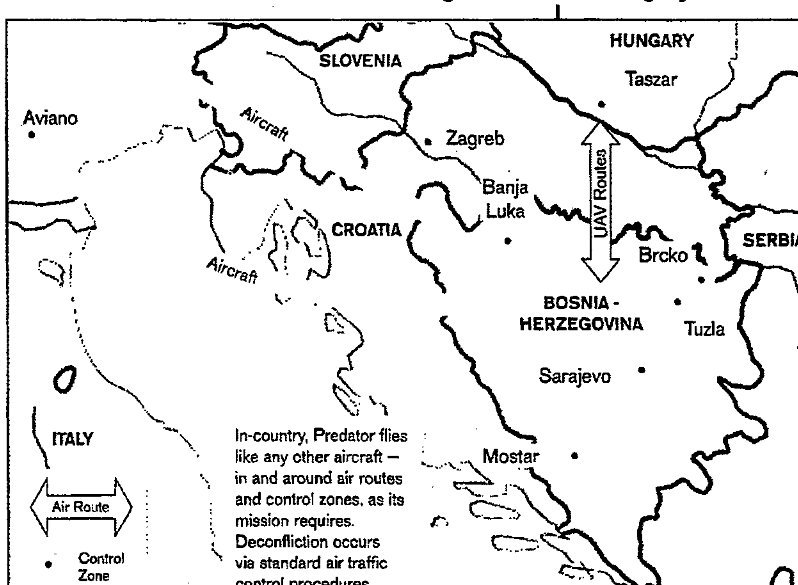
Based at Taszar in Hungary, *Predator* has provided surveillance and reconnaissance support, first for Operation Joint Endeavor as part of NATO's Implementation Force (IFOR), and then for Operation Joint Guard as part of its Stabilization Force (SFOR). Operated by the Air Force Air Combat Command's 11th Reconnaissance Squadron (RS) since September 1996, *Predator* has flown 294 operational missions from March 1996, when Operation Joint Endeavor began, through 30 September 1997. Area and point targets include helicopter staging areas, cantonment areas, mass grave sites, equipment assembly areas, storage sites, and personnel movements (both military and civilian). In the Fall of 1997, *Predator* was assessed as SFOR's best surveillance asset. It provided the following support for SFOR operations and NATO activities:

- Surveillance to assist route planning and force security operations, to include the Pope's visit in April;
- Monitoring trouble spots to help provide early warning of crises;
- Monitoring of polling stations and access routes during September's municipal elections;
- Supporting U.S. Secretary of State Madeleine Albright's October visit to Brcko with security assistance, force protection and force monitoring; and
- High-resolution day/night imaging of weapons cantonment areas, to ensure compliance with the Dayton Accords.

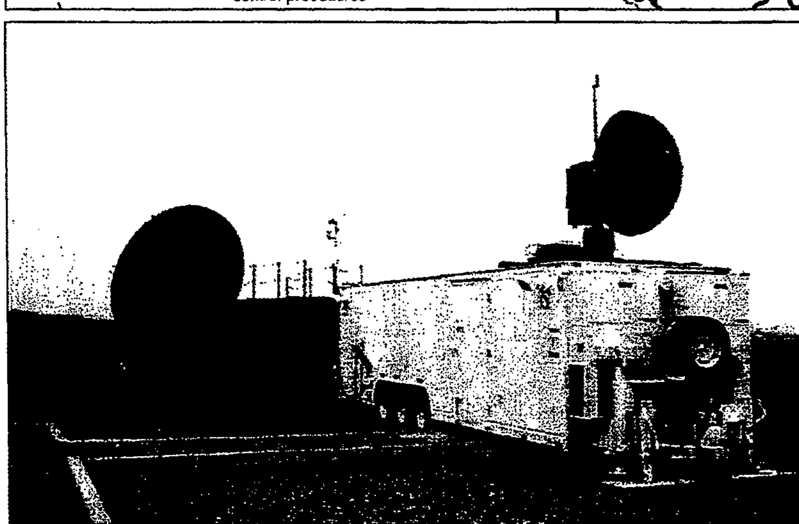


A *Predator* taxis from its hangar in Taszar, Hungary

Airspace Management. From the beginning, integration of *Predator* flights into Balkan airspace has employed time and space control procedures to ensure deconfliction with other air traffic. *Predator* is flight-controlled by its Ground Control Station (GCS) along route- and altitude-specific air corridors through international airspace to and from its operating areas over Bosnia. The air vehicle (AV) takes off into Hungarian airspace, traverses Croatian airspace via a narrow corridor, enters Bosnian airspace via a single fixed-time entry and exit point to perform its missions, and reverses the route for recovery. A combination of established procedures, continuing liaison with air traffic control authorities and real-time coordination of changes assures safety while covering the tasked targets.



Dynamic Retasking. The mission continues to evolve and overall capabilities continue to improve. The 72-hour air tasking message (ATM) cycle time required during *Predator's* first deployment (to Gjader, Albania) has been overtaken by "dynamic" or "in-flight retasking," which allows a tactical commander to direct the AV and/or its sensors, by telephone, while watching their down-linked video. Its imagery is disseminated by a Trojan Spirit II terminal through the Joint Broadcast System (JBS) to theater and international command and control (C2) facilities. This provides near-real-time control of the UAV from virtually anywhere.



Predator's Ground Control Station at Taszar, Hungary

Pioneer Operations

Nine *Pioneer* systems are operated by the Navy and Marine Corps. The Navy's five systems are assigned to VC-6, located at Webster Field, St. Inigoes, MD. The Marine Corps' two systems are assigned to VMU-1 and VMU-2, located at the Marine Corps Air-Ground Combat Center (MCAGCC), Twentynine Palms, CA, and Marine Corps Air Station (MCAS) Cherry Point, NC, respectively. Both Services have one or more deployments under way most of the time. The remaining two systems are located at Ft. Huachuca, AZ (see p. 10).

Pioneer continued its ten-year history of mission support in both operational and acquisition arenas. FY 1997 operational activities are tabulated below. They begin with a return from Bosnia and continue with land- and sea-based deployments throughout the year. Meanwhile, several Marine remote receiving station (RRS) teams remained in Bosnia to help with imagery collection, to include monitoring of potential trouble areas during the September 1997 elections. *Pioneer's* system test and payload support activities are detailed on pages 36 and 39.

Pioneer Operational Deployments and Support

May 96 – Present VMU-2 Bosnia Remote Receiving Station (RRS) support (Three 2-man teams)
Jul 96 – Present VMU-1 Bosnia RRS Support (Four 2-man teams)

Dates	Unit	Deployment	Mission: Support –	Activities / Accomplishments
14 Jun – 29 Oct 96	VMU-1	**First Bosnia land-based deployment** (near Tuzla)	UN IFOR operations with direct intelligence, surveillance, and reconnaissance (ISR)	• Provided **real-time imagery** directly to IFOR units • Used for **dynamic retasking** of units • **Surveillance** of population centers and suspected terrorist training areas, and route **reconnaissance**
24 Jun – 19 Dec 96	VC-6 Det 1	Mediterranean Sea, aboard USS Austin (LPD 4)	Fleet operations: Exercise Dynamic Mix (available for contin-gencies)	• **Real-time reconnaissance/surveillance** of beach for Turkish units and USMC • **Targeting, BDA**. Fully integrated with amphib ops • USMC Cobra crews used *Pioneer* video and pix for **real-time intelligence** on unknown airfield
2 –20 Feb 97	VMU-2	NAS Key West, FL	Joint Task Force (JTF) 6 operations	• Provided surveillance info to Commander JTF 6 for **counter-drug ops**
Feb/Mar Mar/Apr Sep/Oct 97	VC-6 Det Pax	Naval Strike and Air Warfare Center, NAS Fallon, NV	Carrier Air Wing exercises - CVW-1 - CVW-9 - CVW-7	• **Pre- and post-strike reconnaissance** and **BDA**
15 Feb – 9 Mar 97	VMU-1	MCAS Yuma, AZ	Marine Corps Weapons and Tactics Instructor (WTI) course	• Demonstrated direct uplink of live *Pioneer* video to the cockpit of an airborne F/A-18 using Arid Hunter **(= real-time information in the cockpit / RTIC)**
21-25 Apr 12-16 May 20-28 Jun 20-30 Jul 18 Aug – 5 Sep 97	VC-6 Det 2	USS Shreveport (LPD 12) workups	- Training Services - PMINT - COMPTUEX - MEUEX - JTFEX / SOCEX	• JTFEX / SOCEX included support from Aberdeen Proving Ground with a second *Pioneer* system
7 Apr – 23 May 97	VMU-2	MGAGCC, Twenty-nine Palms, CA	Combined Arms Exer-cises (CAX) 5 & 6	• **Close Air Support (CAS)**
6-23 Jun 30 Jun – 14 Jul 97	VMU-1	MGAGCC, Twenty-nine Palms,CA	CAXs 7 & 8	• **CAS**
18 Sep – 21 Oct 97	VC-6 Det 3	USS Denver (LPD 9)	Type Training / COMPTUEX	• Shipboard training and integration

Pioneer's continuing utility is reflected in the fleet's flying time, increased readiness, and decreased accident rate.

Task Force XXI – Advanced Warfighting Experiment

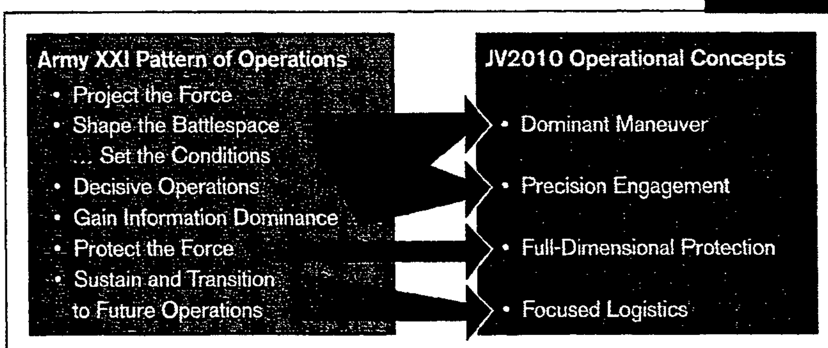
As part of its joint effort to redesign the Army for the 21st century and integrate information technologies in the process, the Army has been conducting a series of digitized Advanced Warfighting Experiments (AWEs) at the National Training Center (NTC) at Fort Irwin, CA. These are designed to develop combat operations for the 21st century. Task Force (TF) XXI, or NTC rotation 97-06, addressed multiple Army objectives that focused on forces, operations, tactics and systems developed around enabling information systems and digital technologies. From 15 through 28 March, the "blue" Experimental Force (EXFOR, the 1st Brigade of the 4th Infantry Division) engaged in force-on-force operations against the NTC's "red" Opposing Force (OPFOR), following several months of prior smaller-unit exercises and training. TF XXI also involved joint participation by Marine Corps, Air Force and Special Operations Forces, which supported the EXFOR.

Among several information-enhancing systems supporting the EXFOR were UAVs:

- Eight *Hunter* air vehicles (AVs), as surrogates for the *Outrider* Tactical UAV; and
- The *Gnat 750* as a surrogate for the *Predator* UAV.

The Army's major combat operational concepts and their linkages to Joint Vision (JV) 2010's concepts are shown to the right.

UAV contributions to the EXFOR's performance are documented below.



UAV Contributions to the TF XXI AWE

The effects of UAVs on the battle were emphasized in testimony by GEN Hartzog, Army TRADOC Commander, before the Senate's AirLand Forces Subcommittee:[1]

> *Unmanned aerial vehicles were one of the big winners at the NTC rotation 97-06. Clearly they are emerging as the next generation of airborne reconnaissance. Technological advances in electronics, materials, propulsion, construction, and communications are bringing about the reality of collection and near- to real-time dissemination of information. The ability of the UAV to penetrate enemy airspace and dwell over and near target areas is essential to Army XXI warfighters and represents a vital link to other reconnaissance vehicles and platforms. The imaging systems of the UAVs allow commanders to detect, identify, and track hostile activity in sufficient time to target with lethal weapons systems or maneuver against or around them, as appropriate, and conduct battle damage assessment. Additionally, the UAV enhances the commander's ability to locate, identify, and track friendly forces to avoid fratricide. In the foreseeable future, UAVs will also give us the capability to detect nuclear, biological, and chemical weapons; see*

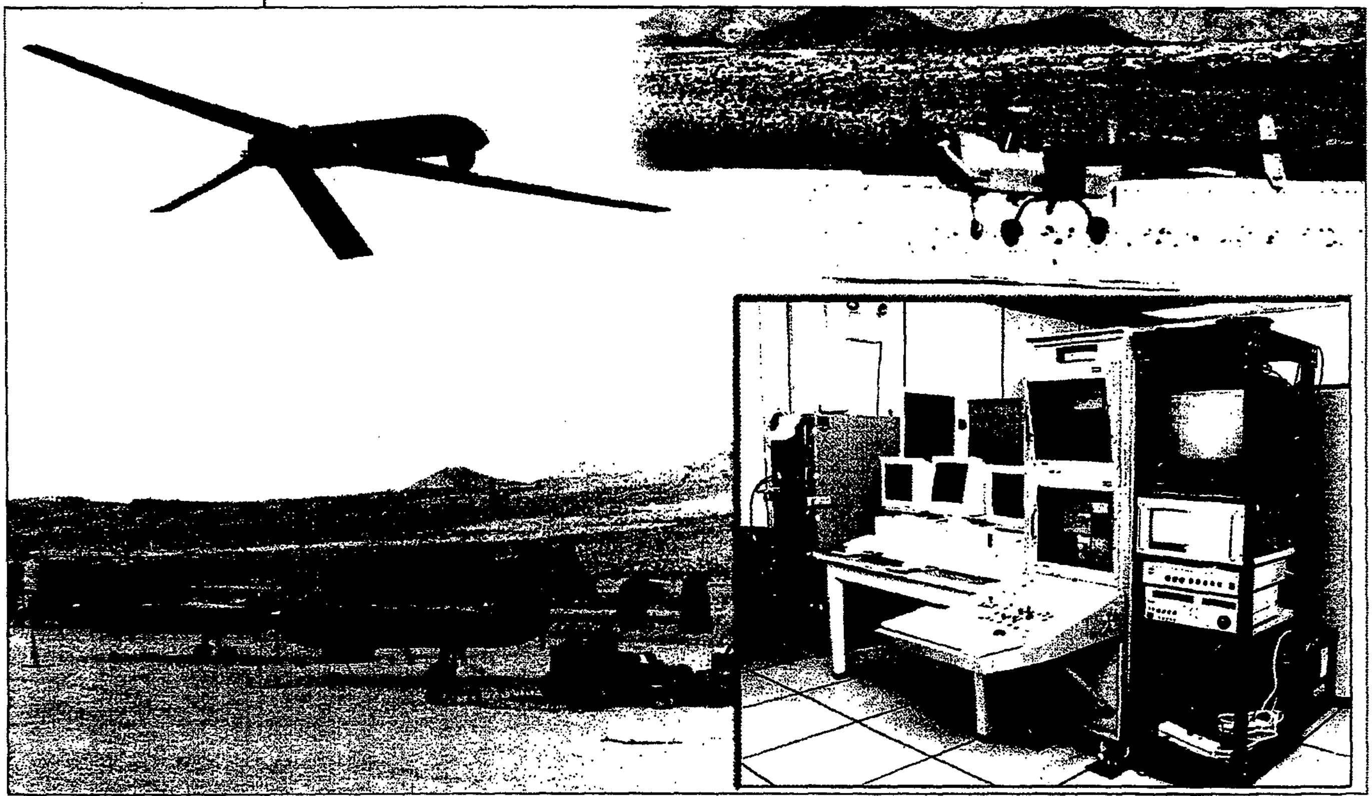
EXFOR soldiers control a tactical UAV

"I will give up a tank battalion for a UAV company."

MG Kern, Commander, 4th Infantry Division, to GEN Reimer, Army Chief of Staff, March 1997

[1] GEN William W. Hartzog, Commanding General, U.S. Army Training and Doctrine Command (TRADOC). Statement before the AirLand Forces Subcommittee, Senate Armed Services Committee, 9 April 1997

"Unmanned aerial vehicles were one of the winners ..."



Hunters, Gnat 750 and TCS supporting EXFOR during TF XXI

into double and triple canopy jungles; and provide low cost and reliable communications and data relay across the battlefield....

Those of us at the NTC noticed that the UAV had an interesting effect on the OPFOR. They spent a lot of time looking for it, and tended to talk about it on the radio as well. That allowed intelligence forces a chance to intercept the conversations and provided much valuable visual and audible data. In very initial reports, the Operational Test and Evaluation Command (OPTEC) notes that the OPFOR reaction to Hunter's presence on the battlefield included movement of vulnerable assets more often, dispersal of equipment over larger areas, maintenance of key assets in no-fire zones, dedication of SA-8s and SA-9s to the UAV fight, delayed movement to defensive positions to the last possible moment, and attempts to continually track the UAV from audio signature.

The Secretary of Defense and other senior military and civilians within the Department of Defense were also favorably impressed with the performance of the unmanned aerial vehicles, calling the UAV the "cream of the crop at the NTC" and "the future of the Army."

Operators and soldiers were enthusiastic about the system as well. The UAV provided a level of intelligence never before available to commanders.

During the exercise, *Hunter* flew 56 sorties for 282 hours in the tactical UAV role, while the *Gnat 750* flew 5 sorties for 23 hours as a medium-altitude endurance (MAE) UAV.

In addition to the UAVs, the Tactical Control System (TCS) also participated in the exercise, as part of its program definition phase. It demonstrated the following:

- Passive receipt of *Gnat 750 (Predator)* and *Hunter* (TUAV) imagery;
- Multiple UAV management; and
- Connectivity to other participating command, control, communications, computers and intelligence (C4I) facilities.

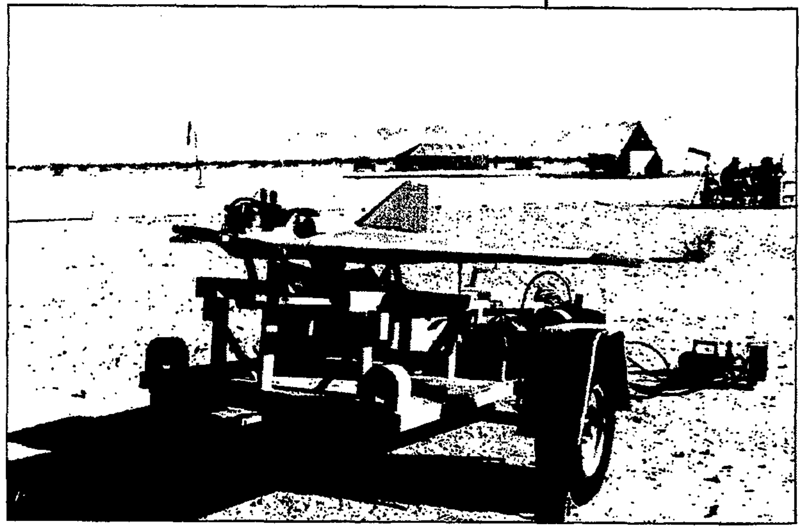
In addition to the Army's appreciation for UAVs' impact on the battlefield, they are increasingly recognizing the need for the fusion of UAV products with other intelligence, surveillance and reconnaissance (ISR) capabilities, and for more training.

Hunter Warrior

The Marine Corps' Warfighting Laboratory conducted the Hunter Warrior AWE at Camp Pendleton, CA, in early March 1997. This exercise, based on concepts from the USMC's "Maneuver from the Sea," demonstrated the ability of a small, highly mobile force to evade and fend off a larger one with the aid of advanced computer and surveillance assets.

The Blue Force's 13 surveillance and sensor systems included the *Exdrone* UAV, or "*Dragon Drone*." An Enhanced Combat Operations Center at Camp Pendleton coordinated the different fire support systems. Blue's tactics were to overwhelm the OPFOR with simulated strikes from long-range precision weapons provided by Navy vessels offshore and other Marine Corps fire support sessions, cued by *Exdrone* and other sensors. The "harassing" effect of multiple sensors caused the OPFOR to experience a "fish-bowl" effect — the feeling of being watched all time.

Exercise results showed that the right equipment and technologies, used well, can greatly help a small expeditionary force to overcome a larger, more heavily armed foe.



Exdrone on its launcher at Hunter Warrior

Ulchi Focus Lens

Ulchi Focus Lens 97, a joint and combined-force command post exercise for defense of South Korea, was conducted in August 1997. Both UAVs and the TCS were simulated by the Multiple UAV Simulation Environment (MUSE) system (see p. 39). MUSE's command and control component, acting as a TCS surrogate, demonstrated control of simulated *Predator*, *Outrider*, *Hunter* and *Pioneer* UAVs performing surveillance and reconnaissance functions for the friendly force. TCS tasks were those that will be provided when the system is operational, such as air vehicle/payload control and the message/imagery transmission functions that are key to intelligence and target data dissemination.[2]

[2] Tactical messages were transmitted to the Automated Deep Operations Coordination System (ADOCS), All-Source Analysis System (ASAS), and Contingency Theater Automated Planning System (CTAPS). UAV imagery was transmitted to the 5D server, Closed Circuit Television (CCTV) and Video Imagery Exploitation Workstation (VIEWS) at exploitation sites in South Korea.

Other Exercises and Activities

From 28 May to 31 October 1997, the Naval Strike and Air Warfare Center at NAS Fallon, NV, focused on Navy UAV concept of operations (CONOPS) development, using four *Hunter* UAVs (as a "light" system) in a variety of roles and scenarios. A summary of other UAV participation in exercises further indicates their increasing range of mission applications and military utility, as shown in the following table:

Exercise / Activity	UAV Mission / Functions	UAV	Date
Environmental Survey	Artillery encroachment	Pointer	Oct 96
Navaho Nation Building	Natural resource monitoring (three activities)	Pointer	FY97
Survivability Demonstration	Survivability	Pointer	Nov 96
NASA Air Sampling	Air sample collection	Pointer	Feb 97
Hunter Warrior	Reconnaissance, fwd handoff of targets, ground sensor dispensing	Exdrone	Mar 97
DESFIREX	Tactics, techniques, procedures for target location & artillery adjustment	Exdrone	Mar 97
Ranger Battalion Exercise	Artillery adjustment	Pointer	May 97
Airborne Forces Entry Exercise	Operational force support	Pointer	May 97
Roving Sands	Laser designation and range finding	Hunter	May 97
NAS Fallon Training	Laser designation and range finding / personnel recovery	Hunter	Jul 97
Woodland Cougar	Personnel recovery	Exdrone	Aug 97

Operations and Training

Joint UAV Training Center (JUAVTC) — Ft. Huachuca, AZ

The JUAVTC houses Delta Company, of the Army's 304th Military Intelligence Battalion (MI Bn). Delta Company conducts both initial and advanced training on the *Hunter* UAV for air vehicle (AV) and payload operators and for electronic and mechanical system maintainers. It graduated 146 students in FY 1997 and projects 198 for FY 1998.

The company's mission also includes:

- Development of UAV doctrine and training materials;
- Preparation of Army personnel for worldwide UAV support; and
- UAV support for Army Force XXI initiatives, AWEs, and system developments.

Special activities for this past year included:

- A long-range mission test, where a locally launched *Hunter* was transferred to a deployed Forward Control Element and usable imagery transmitted well beyond normal operating ranges;
- Incorporation of UAV relay flight training into its training syllabus; and
- Targeting and BDA support for a Navy Tomahawk test launch.

NAMTRAGRUDET — Ft. Huachuca, AZ

A detachment of the Naval Aviation Maintenance and Training Group (NAMTRAGRU), formerly the Defense UAV Training Center (DUTC), operates two *Pioneer* systems. As a tenant in the JUAVTC facility, it coordinates closely with the 304th MI Bn. It provides operator and maintainer training on the *Pioneer* UAV for both Navy and Marine Corps personnel. During FY 1997, the group trained 138 students and plans to train 109 during FY 1998. Its graduates then go on to staff the Navy's and Marine Corps' operational *Pioneer* units (VC-6, and VMU-1 and VMU-2, respectively; see p. 6).

11th RS:

- Activated August 1995 at Nellis AFB, NV.
- Assumed operational control of *Predator* assets in Bosnia at Taszar, Hungary, 2 September 1996.

11th Reconnaissance Squadron (RS) — Indian Springs, NV

The 11th RS operates *Predator* for the Air Force at Indian Springs Auxiliary Air Field, NV (near Nellis AFB). Its activities are divided between *Predator* support for NATO forces in Bosnia (see pp. 4-5) and training *Predator* operators and crews. Both activities are being pursued with limited assets, pending receipt of production and additional refurbished assets. Accomplishments to date reflect the current maintenance robustness of the *Predator* system.

Predators have flown more than 330 missions and 2,600 hours in general reconnaissance support for Bosnia operations since the 11th RS assumed operational control of *Predator* assets (see *UAV Annual Report: FY 1996*, pp. 7 and 9). The deployed unit currently has two AVs and one GCS; a third AV was lost in August 1997 while on short final approach following an in-flight emergency. However, by controlling that *Predator's* recovery to avoid populated areas and any collateral damage, its operator demonstrated that UAVs could be flown as safely in restricted airspace as manned aircraft under equivalent conditions.

The 11th operates two more AVs and one GCS at Indian Springs, where it has graduated six payload instructors and 12 AV pilots to date, with 6 more pilots graduating in December 1997.

15th RS Standup Ceremony

15th Reconnaissance Squadron (RS) — Indian Springs, NV

This new squadron was activated on 1 August 1997. It joined the 11th RS, near Nellis AFB, NV, as the Air Force's second *Predator* operating unit, though it will not receive actual systems until a year later. The Air Force made it operational 26 months earlier than expected to ensure the Service's readiness to operate UAV assets as soon as they are available.

Special Activities

Exdrone to Dragron Drone: From Exercise to Operations

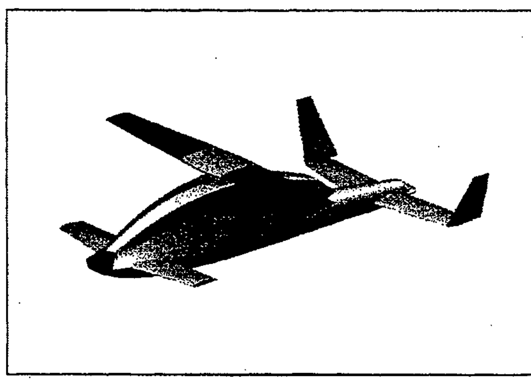
Following *Exdrone's* strong performance during the Hunter Warrior AWE in March 1997, the Marine Corps plans to make it seaworthy for operational experimentation aboard amphibious ships. The Marine Corps Warfighting Lab is upgrading ten *Exdrones* as *Dragon Drones* with a shipboard launch and recovery capability, heavy fuel engine, forward-looking infrared (FLIR) sensor and differential global positioning system (GPS). The Marines plan to deploy them on at least one ship for demonstration purposes, beginning in FY 1998.

VTOL Evaluation

The Congress provided $15 million in FY 1997 to fund a vertical takeoff and landing (VTOL) UAV demonstration. The DoD determined that this activity required a competitive procurement and the Navy released a Broad Area Announcement (BAA) in October 1997. It plans to award one or more VTOL UAV contracts in December 1997 for demonstration(s) during FY 1998. The Navy's objectives are to evaluate current VTOL UAV maturity and technology risks associated with a system development for naval operations.

Advanced VTOL Technologies Program

For FY 1998, the Congress has funded the start of a demonstration program for future VTOL UAV technologies, to include a stopped-rotor high-speed VTOL platform concept. This concept is embodied in a canard rotor/wing (CRW) design called *Dragonfly*. The CRW will perform as a helicopter for takeoff and landing and as a fixed-wing aircraft (using its stopped rotor as a wing) for high-speed cruise. *Dragonfly's* potentially high-payoff technology may be applied to future manned as well as unmanned systems.



PEO(CU) Move to Patuxent River, MD

The Navy's Program Executive Office for Cruise Missiles and Joint UAVs (PEO(CU)), moved from Arlington, VA, to NAS Patuxent River, MD, in June 1997. Its UAV Joint Program Office (JPO) completed its transition in July. The overall move, which included the Naval Air Systems Command (NAVAIR), was made in compliance with the Base Realignment and Closure (BRAC) decisions of 1993. PEO(CU) maintains a liaison office in Arlington, VA.

TMD Hunter/Killer Experiment

Army Special Operations Forces, using S-TEC *Sentries* and AeroVironment *Pointers*, are planning to participate in Ballistic Missile Defense Organization (BMDO) -sponsored exercises during the winter of 1997 – 98. The UAVs will be the "hunters" in active Theater Missile Defense (TMD) hunter/killer teams attempting to find and destroy tactical ballistic missile launchers before they can launch their missiles.

Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS)

The Office of Naval Research (ONR) established CIRPAS in Spring 1996 to provide UAV flight services to RDT&E customers in their development, testing and evaluation of UAV technologies, payloads, and system capabilities. Assets include the *Pelican* (a Cessna 337 derivative) and *Aerosonde* low-altitude and the *Altus* high-altitude AVs, satellite communications, a GCS, air traffic control relay radios, and selected monitoring and payload packages. Assets may be leased as turn-key UAV operations to support research. CIRPAS is associated with the Naval Postgraduate School in Monterey, CA, and will operate from Ft. Hunter-Liggett from 1998 on.

Battle Labs

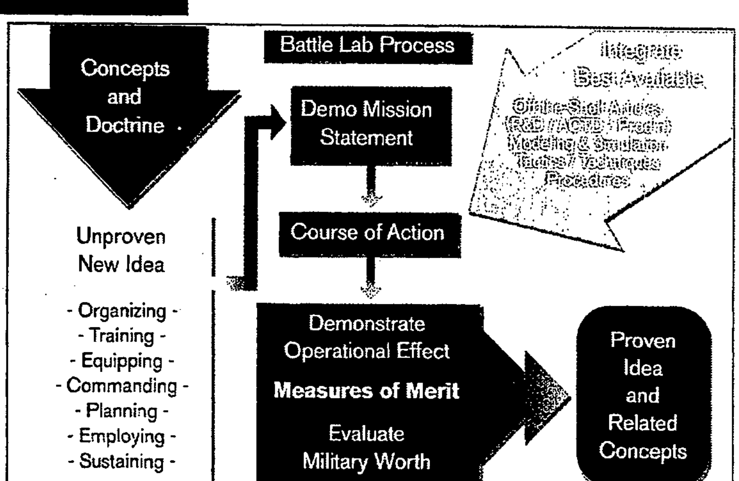
DARO sponsored the first joint-Service UAV Battle Lab Symposium 16 – 17 April 1997. Representatives attended from five of the Army's Battle Labs, the Naval Strike and Air Warfare Center (NSAWC), the Marine Corps Warfighting Lab, and the Air Force's UAV Battlelab; also from the Services' UAV staff and program offices, and from other labs.

The Services' battle labs exist to infuse operational thinking into critical mission areas. By focusing on innovative concepts supported by technology, they hope to generate imaginative and "out-of-the-box" ideas from the field — from the warfighter — and conduct operationally oriented experiments and demonstrations. Current UAV activities among the battle labs are summarized below.

Army Battle Labs. The Army established its battle lab organization in 1992. While the Battle Command Battle Lab (Ft. Huachuca, AZ), or BCBL(H), had the lead on UAV activities in the Task Force XXI operational exercise (see pp. 7-8), no one Army lab is in the lead for UAVs. Specific activities include examining UAV operations:

- Integrated with manned aircraft;
- As rear-area security platforms;
- Supporting deep strike operations and their battle damage assessment (BDA);
- As airborne communications nodes;
- As platforms for chemical/biological and mine detectors.

Additional BCBL(H) initiatives involve:



- The Combat Synthetic Test and Training Assessment Range (CSTTAR), which tests video and data transfer between the MUSE and the Army's All-Source Analysis System's Remote Work Station (ASAS RWS); and
- An experimentation program to examine and assess UAV tactics, techniques and procedures (TTP) used by Army tactical units.

Navy. The NSAWC, at NAS Fallon, NV, is developing Navy UAV CONOPS (see p. 9).

Marine Corps Warfighting Lab. The Commandant established this lab at Quantico, VA, in 1996. Its UAV initiatives have focused on tactical support for lower-echelon units via small UAVs, such as the *Dragon Drone*, *Pointer* and *Sender* UAVs. In addition, the Marines are examining UAV dispensing of leaflets and non-lethal agents, such as pepper spray and tear gas.

Air Force Battle Labs. The Air Force has established six battle labs this past year. The UAV Battlelab, which stood up officially on 1 July 1997 at Eglin AFB, FL, already has three initiatives underway:

- Demonstrating UAVs as long-endurance threat warning and location platforms to support Suppression of Enemy Air Defenses (SEAD) operations;
- Flying a QF-4 drone with a Traffic Alert and Collision Avoidance System (TCAS) aboard, to show UAV compatibility with airspace safety requirements; and
- Exploring UAV support for "bare base" security operations, where quick perimeter surveillance and threat detection could be vital precursors to more permanent measures.

This third initiative is a cooperative effort with the Force Protection Battle Lab, which stood up in June 1997 at Lackland AFB, TX. This battle lab's two-year UAV security demonstration project is looking more broadly at local area surveillance, detection of explosives, and lethal and nonlethal ways of neutralizing threats.

DARO plans to convene another joint-Service UAV Battle Lab Symposium in 1998, again to share ideas and foster synergies from complementary activities.

Evolving Missions and Concepts

Small Scale Contingencies (SSC)

SSCs are assuming a larger role in the DoD's planning and preparations. In addition to surveillance and reconnaissance functions for traditional military operations, these functions are being applied to broader contingency scenarios where U.S. and allied forces may not be directly involved. These operations include:

- Humanitarian Relief Operations (HUMROs);
- Noncombatant Evacuation Operations (NEOs); and
- Peacekeeping Operations (PKOs).

As evidenced by successful Bosnia operations, during the past two years, UAVs are able to overfly trouble areas well beyond friendly force lines. This makes them natural assets for the cost-effective, nonthreatening performance of extended surveillance and reconnaissance functions.

In June 1997, the Commander-in-Chief of European Command (CINCEUR) requested options for a small-footprint, easily deployable UAV to support Joint Task Forces (JTFs) conducting NEOs and HUMROs, using a sub-Saharan Africa scenario. In response, DARO prepared information on numerous DoD- and industry-developed tactical UAVs for EUCOM staff review. In November 1997, DARO and EUCOM representatives are visiting a number of industry contractors to gather additional information for further assessment.

Real-Time Information to the Cockpit (RTIC)

RTIC, or sensor-to-shooter linkage, has been a crucial need since allied forces' largely unsuccessful efforts to target mobile missile launchers during the Persian Gulf War of 1991. The Air Force has conducted several demonstrations using high-data-rate (HDR) satellite communication channels to link intelligence and tactical assets in the targeting of mobile, fleeting targets.

Meanwhile, during VMU-1's *Pioneer* deployment to support a Marine Corps Weapons Tactics Instruction (WTI) exercise at Yuma, AZ during February and March 1997, VMU-1 demonstrated the direct uplink of live *Pioneer* video to the cockpit of an airborne F/A-18. As such demonstrations increase in number and mission application, UAV roles and capabilities will also expand.

Boost-Phase Intercept (BPI)

The Persian Gulf War of 1991 reinforced the value of active theater missile defense (TMD). Post-war analysis further indicated the benefits of intercepting enemy missiles early, namely in their boost phase where their launch plume would make them easier to see. Now, a May 1997 report by the Ballistic Missile Defense Organization (BMDO) looks at the feasibility of using armed UAVs as TMD platforms.

Among other options, the study examined modified *Global Hawk* configurations as interceptor missile platforms. By replacing its reconnaissance sensors with an infrared search and track sensor and mounting missiles under the wings, analysts traded some of *Global Hawk's* fuel and endurance for the extra weight of the weapons packages. The resulting systems could still provide significant on-station endurance, depending on range from base. Challenges include assuring separation of interceptor from UAV at launch, continued target tracking and interceptor guidance during the engagement, and how much self-protection the UAV might need. Costs for an optimized *Global Hawk* were projected in the $1- to $2-billion range for a 24- to 74-UAV force size (plus ground stations), which would compare favorably with any similarly proposed capability to date.

This and other studies of armed UAVs, such as the Uninhabited Combat Air Vehicle (UCAV), are beyond DARO's responsibility for nonlethal UAVs. However, the clear advantages of UAVs as multipurpose platforms are becoming increasingly well-recognized. Broader mission applications for *Global Hawk* and other developmental UAVs are fueling an expanding demand.

An Expanding Analytic Base

DARO's Airborne ISR Analysis Program

In late-FY 1996, DARO formed the DARO Architecture Development Team (DADT) to develop an Objective Architecture and investment strategies for the migration of "stovepiped" airborne reconnaissance assets by the year 2010. During the past year, the DADT has participated in or reviewed ISR studies DoD-wide and performed its own architectural and force mix study, with investment strategy, culminating in a draft system roadmap to achieve its goal.

To reach this point, the DADT established a broad-based modeling, simulation and analysis (MS&A) capability, which used both tools and an iterative methodology to provide insights for the initial development of the DARO's 2010 force structure projection. Selected systems, combined as architectures for given scenarios and yielding information products, result in recommended force mixes that are subjected to cost/benefit analyses that generate program requirements for future systems. More robust MS&A capabilities will strengthen and extend initial insights, thus enabling more comprehensive system, force mix and architectural performance assessment. Continued iteration and refinement of tools and techniques will eventually support both in-depth and quick-turn systems analyses.

National / Commercial + Manned + Unmanned
Reconnaissance Systems

Rationalize Requirements

Airborne Force Mix Option Studies		
Agency	**Study**	
DARO	DADT	DARO Architecture Development Team
NRO/DARO	APEX	Airborne Performance Evaluation Exercise
OSD	QDR	OSD Quadrennial Defense Review [a]
ASD(C3I)	CMA	C4ISR Mission Assessment
USA	ATIS	Army Tactical Imagery Study
JWCA/J-2		Recce 2010
NRO	SAMS	Spacecraft-Aircraft Mix Study
NIMA	AIMS	Aircraft Imagery Mix Study
DIA	MAIS	Military Assessment of Imagery Systems
NSA/OSD	SMS	SIGINT Mix Study
Services		Wargames [b]
DSC	Study II	C4ISR Impacts on Strike Warfare

[a] No force mix specified [b] Tend to support UAVs across the board

DoD Force Mix Studies

Most current DoD studies of aircraft, UAV and/or satellite force trades are "single-INT." They do not show the benefits of multi-sensor cross-cueing, or of future advanced processing and communications technologies. In addition, many of the studies' results are not easily comparable. Nevertheless, several provide at least first-order support for DARO projections, which envision a UAV force mix of about 240 tactical UAVs, 48 Predators, and 35 HAE UAVs.

DSC Studies. Two studies by DoD's C4ISR Decision Support Center (DSC) specifically involve UAVs. "Study II" addressed C4ISR impacts on Strike Warfare, to include the use of UAVs in densely defended areas for the Suppression of Enemy Air Defenses (SEAD) mission. "Study III" addressed Communications UAVs (CUAVs), projecting *Predator* and *Global Hawk* with communications packages operating with or in place of other surface- and space-based communications systems. It concluded that:

- By augmenting other links, CUAVs could improve theater and tactical communications, especially for mobile or isolated users; but —
- CUAVs could not replace satellite communications for strategic (inter-theater) scenarios with high-capacity long-haul traffic.

Recommendations included acceleration of "proof-of-concept" activities and demonstrations, and development of an unmanned airborne communications node (see p. 42) and comprehensive communications architecture.

AAN Wargames. The "Army After Next" (AAN) project conducts broad studies of future warfare, to include projecting an advanced-technology family of UAVs. In its January 1997 strategic war game set in 2020, for example, Red attacked Blue's space systems all-out. Blue offset their loss by using other assets, including high-altitude UAVs, to maintain tactical knowledge dominance by helping to net the distribution of vital information.

DARO's Objective Architecture and 2010 Force Structure Projection

DARO has recently developed the DoD's first fully integrated airborne reconnaissance architecture to achieve the goal of Information Superiority, which underpins the operational concepts of JV 2010.[3] This architectural framework presents a vision of the entire *Global ISR Enterprise* to support our National Military Strategy, namely to fight and win two nearly simultaneous military theaters of war (MTWs), as well as to support peacetime engagement, deterrence, and conflict prevention. The DARO architecture envisions a complementary, balanced mix of airborne and overhead ISR assets. Its attributes are shown in the table above-right.

Key Attributes of the DARO's Objective Architecture
• Ubiquitous internetting, "network-centric" concept of operations
• Leveraging of commercial and coalition information products and services
• Rapid reconfiguration of operating domains
• Low "cost of entry" (i.e., rapid injection of new capabilities)
• Real-time delivery of information to the warfighter
• Collaborative planning (vice requests for information)
• Warfighter becomes the system "front end" and analyst of choice
• Enterprise-based, market-driven customer service operations

UAV Types. The projected force mix that supports the DARO's airborne reconnaissance architecture comprises five types of UAV for 2010:

- Multi- or single-INT HAE UAV (based on *Global Hawk);*
- HAE Airborne Communications Node;
- *DarkStar* low-observable HAE UAV;
- *Predator* (with enhancements); and
- Tactical UAV in large numbers.

Force Migration. With the evolutionary acquisition of technology-enabled and operationally demonstrated capabilities, DARO projects a gradual migration towards UAV dominance in airborne ISR:

- HAE UAVs to initially augment and eventually replace manned platforms in high-altitude, long-range/endurance, all-weather sensor ISR operations:
  - HAE UAVs (with IMINT and SIGINT) for standoff missions (to replace the U-2);
  - *DarkStar* for penetration missions into heavily defended areas;
- *Predator* to be produced and enhanced to augment manned systems for medium-altitude missions;
- Tactical UAVs to augment low- and medium-altitude tactical platforms; and
- Both *Predator* and *Outrider* to be replaced by updated versions as early as 2010.

General Migration Trends. As selected manned platforms are also improved (or replaced by a single airframe to reduce logistics costs), the overall manned-unmanned airborne reconnaissance force inventory is actually increased to meet the projected two-MTW demands on ISR in the 21st century. Beyond 2010, further incremental replacements or new developments may be fielded, to include a reconnaissance variant of, or pod for, an uninhabited combat air vehicle (UCAV) in the post-2015 time frame.

In addition, information networks, communications links and surface C4I systems also need to migrate — to the future Distributed Reconnaissance Infrastructure (DRI) part of the Global ISR Enterprise to keep pace with today's explosive growth in information generation. Adoption of improved communications technology will pace the migration from current "stovepipes" to an integrated information architecture responsive to the needs of the warfighter. Today's collection of single-INT, Service-specific ground/surface systems connected mostly by point-to-point links will successively lead to:

- Multi-INT interoperable systems with distributed workgroups collaborating through network interconnections;
- The addition of software applications that extend Processing, Exploitation and Dissemination System (PEDS) capabilities into non-DARP systems; and
- Ultimately, fully networked operations supporting "network-centric" warfare.

With their flexible payloads and links, UAVs will be an integral part of this architecture.

[3] Joint Vision 2010: Full spectrum dominance, via —

- Dominant Maneuver
- Precision Engagement
- Full-Dimensional Protection
- Focused Logistics

UAVs and the Acquisition Environment

Acquisition reform and streamlining have been underway for several years. Advanced Concept Technology Demonstrations (ACTDs) are designed to get mature technologies into the hands of users for early evaluation of military utility — before subscribing to a full-scale acquisition program. Essentially, contractors demonstrate and support come-as-you-are systems to combined operator-developer evaluation teams during a two-to-four-year program period (vice the normal ten-year-plus duration of a normal acquisition program). ACTD systems were to include non-developmental item (NDI) and commercial or government off-the-shelf (COTS/GOTS) components where practical.

ACTD OUTCOMES

1. If User Not Prepared to Acquire – Options:	2. If User Wants – One or a few:	3. If User Wants – In Quantity:
a. Terminate (not cost-effective) b. Place "on the shelf" (time not right) c. Develop further (good idea; improve it)	• Fix demonstrator to be operationally suitable; replicate as required	• Enter acquisition process at the appropriate stage

Depending on the operational assessment, one of three ACTD outcomes is envisaged (at left).

DARP UAVs

Predator, DoD's first ACTD and first to transition to a formal acquisition process, fit outcome #3. DoD's other three UAV acquisition programs are also ACTDs:[4]

- *Global Hawk* and *DarkStar* are the two air vehicle components of the High Altitude Endurance (HAE) UAV ACTD, managed by the Defense Advanced Research Projects Agency (DARPA); and
- *Outrider* is the air vehicle in the Tactical UAV (TUAV) ACTD, managed by the Navy's Program Executive Officer for Cruise Missiles and UAVs (PEO(CU)).

An ACTD IS:

- A way to get technology into the hands of operators early, for operational evaluation

An ACTD Is NOT:

- A means of bypassing necessary acquisition processes as a shortcut to deployment

ACTD Lessons Learned

Lessons learned from *Predator* (and other ACTD) experiences are being applied to the ACTD process in general. As noted in last year's report:

> ... the *Predator* ACTD had no projected procurement budget: at its outset (January 1994), nobody knew how well it would perform. Further, while ACTD unit costs may be low (often representing off-the-shelf [OTS] components), militarizing some capabilities and realizing logistics support needs both increase program acquisition costs. For example, while an ACTD *Predator* demo system cost about $15 million, a combat-ready production system (with configuration changes, added payload and link subsystems, and full integrated logistics support [ILS] provisions) requires about twice that sum.

By comparison, the TUAV ACTD includes funding provisions for transition plus significant out-year procurement funds. Eight IPTs [Integrated Product Teams] are active to assure integrated system development. Thus, rather than committing prematurely to a production program before the ACTD results are known, early planning and an LRIP option will optimize the ACTD-to-formal acquisition transition process if the ACTD is deemed successful.

With another year's experience, during which *Predator* completed its transition to formal acquisition and the TUAV ACTD completed its first year, these initial findings have been reinforced. For example, we have learned that DoD must plan for post-ACTD procurement and support well before a complete assessment of military worth — otherwise the process loses time while acquisition prerequisites are "backed" into place. This is not equivalent to a pre-commitment to proceed; instead, it involves the concurrent completion of key program/budget and operational preparations for acquisition. Our goal has been to reduce unnecessary cost-of-ownership burdens — up front in the development and evaluation periods.

Predator

Specific success factors included:

- The importance of technical maturity in avoiding "surprises";
- A single, highly qualified program manager for the duration of the ACTD;

[4] *Pioneer* is an operational system now fully funded by the Navy, and *Hunter* is being used for concept development by the Army and other Services.

- An early opportunity to demonstrate military worth before requirements "grew" too far.

Predator's value in support of Bosnia operations, while still in ACTD status, is well-known. This, in turn, provided an "umbrella" under which operational shortcomings or needs could be identified and resolved. Two additional lessons were derived from this experience:

- The need for timely development and coordination of airspace management practices (both at home and abroad); and
- The importance of logistics, both as an underlay for a successful ACTD and in assuring fielded system suitability.

Outrider

By comparison, the TUAV ACTD *(Outrider)* evolved from an already-planned acquisition program, the Maneuver UAV. It faced the challenge of meeting both Army and maritime requirements with one air vehicle while meeting strict production unit cost thresholds. Also, it was perceived as an "off-the-shelf" system, both to enable early fielding and to meet cost limits. Thus, when significant engineering was required to meet range, engine and shipboard suitability goals, the program fell several months behind schedule. Since that time, a dozen successful flights have both validated its key subsystems and identified capabilities that were "too hard" to attain in a timely manner. For example, a gasoline engine has replaced the heavy fuel engine (HFE) option for the balance of the ACTD, with further HFE development to be consolidated in a separate effort.

HAE UAVs

In contrast, both *Global Hawk* and *DarkStar* were envisioned from the start as needing significant development to work as systems. On the other hand, the operational capabilities projected for each vehicle offered such operational benefits that, if the ACTD approach could enable an early assessment of their military worth, higher risks were well warranted. During this past year, both programs experienced delays for technical problems, but the year delay for each program will still enable their operational evaluation several years earlier than a traditional acquisition program.

A more general set of ACTD lessons learned is listed below.[5]

[5] See also RAND study MR-899-OSD, *The Predator ACTD: A Case Study for Transition Planning to the Formal Acquisition Process*, to be published Fall 1997.

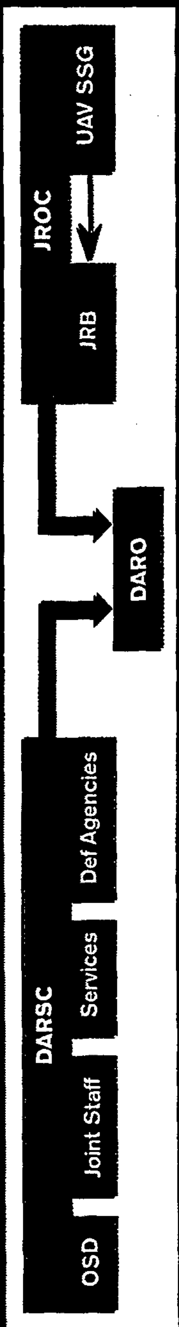
ACTD Issues	Needed to optimize ACTD organization, scope, and conduct:
Choice of demo and operational mgrs	The right people with the right organization relationships, working well together (as in the *Predator* ACTD)
Government program office	Small, effective organization of veteran experts; MOAs to gain outside support
Program control measures	Flexibility and creativity; informal communications; few CDRLs (but enough for supportability planning)
Choice of lead-Service	Lead Service chosen early — to take full part in the ACTD, help evaluate military utility
Declaration of military utility	DoD-level policy and process to guide this evaluation
Funding stability	With tight schedule / high tempo, funding stability throughout the ACTD
Personnel requirements	Personnel skills and training established early (along with Lead Service)
Operational test agency (OTA)	Early involvement (especially by Lead Service OTA); ops / contingency testing is highly beneficial for all

Transition Issues	Completed by end-ACTD to facilitate transition to full acquisition: [a]
Supportability	Key logistics planning as basis for production system design, O&S processes (for residual + production systems), and LCC determination. Involve maintainers early
Producibility	Assurance that post-ACTD design can be produced to desired quantity, rate, and unit cost
Program oversight	Continued OSD mentoring to assure appropriate management organization, sustain user interest / priority
Funding / affordability	Early LCC estimate as input to ACTD decision, to avoid surprises, and to support PPBS wedge for timely acquisition
ORD	Draft to guide military utility evaluation and quantify performance, design, and 'ility goals for transition / acquisition. (A CONOPS is necessary, but not sufficient; the rigor of the ORD process is necessary to define and trade requirements)
Test planning	Initial DT&E plan, plus documented feedback from ACTD assessments

[a] **Note:** *Additional ACTD resources may be needed to support these activities, under the aegis of a Transition IPT.*

UAV Management and Oversight

Several DoD organizations have played continuing roles in the oversight and guidance of UAV capabilities, acquisition, operation, force mix and resource allocations during FY 1997.



Defense Airborne Reconnaissance Office (DARO)

DARO is in its fifth year as DoD's single focal point for improvement of airborne reconnaissance capabilities, reporting to the Under Secretary of Defense for Acquisition and Technology (USD(A&T)). DARO has OSD-level oversight responsibility for airborne reconnaissance architecture determination and systems interface requirements. Accordingly, it develops and coordinates policies and standards to ensure system interoperability, performs system-level trades to support architectural migration and acquisition decisions, and provides planning and resource guidance for the DoD Components' acquisition programs. These programs constitute the Defense Airborne Reconnaissance Program (DARP), and are funded through Defense-wide and DoD Component budget accounts. They encompass manned and unmanned aerial vehicles, sensors and links, their ground stations, and modification activities.

Defense Airborne Reconnaissance Steering Committee (DARSC)

The DARSC is the DoD-wide corporate body that provides executive-level oversight and guidance to the DARO. It is chaired by the USD(A&T); vice chair is the Vice Chairman of the Joint Chiefs of Staff (VCJCS). It meets as necessary to resolve major airborne reconnaissance issues.

Joint Requirements Oversight Council (JROC) and JROC Review Board (JRB)

The JROC reviews operational requirements representing the interests of the operational or warfighting community and its commanders-in-chief (CINCs). The JROC's Chairman is the VCJCS and the JRB is its staff-level review and coordination body. During FY 1996, the JROC issued ten memoranda (JROCMs) addressing UAV priorities and key issues, and providing its assessments and recommendations. Its FY 1997 JROCMs are summarized below.

JROCM-	Summary		
159-96 23 Oct 96 **UAV TCS Key Performance Parameters (KPPs)**	**Threshold** – Support mission planning and execution, and data dissemination for TUAV and MAE UAV – Interoperable with select C4I systems (per Joint Technical Architecture) – Simultaneous flight and payload control of ≥ 2 AVs, BLOS, using 1 TCS – Interoperable with different UAVs and payloads across 5 levels of interaction		**Objective** – And support data collection from HAE UAV – Same – Same – And multiple platforms/ payloads simultaneously
173-96 12 Nov 96 **Updated UAV Priorities**	**#1: Tactical UAV** – Remains JROC's highest priority; also, maintain Pioneer as "bridge" and accelerate TCS development to parallel Outrider's and also support Predator **#2: Predator** – Transition/fielding to meet the MAE requirement; 16 systems required to meet all needs **#3: HAE UAVs** – With Air Force as lead Service, and CGS as HAE UAV ground station		
007-97 13 Jan 97 **Predator's KPPs**	**KPP** • Mobility • Presence (from FLOT to rear of 2d echelon • Search, detect, recognize tactical targets • GCS receive / process / disseminate	**Threshold** – Components via C-130 – Continuous 24-hr intelligence (with on-station relief) – EO, IR, SAR sensors at 30,000 ft slant range – From a single AV	**Objective** – ≤ 2 C-141 loads – (Same) – At 60,000 ft slant range – From multiple AVs
011-97 3 Feb 97 **UAV TCS ORD**	**UAV TCS ORD** General description of operational capability; threat; shortcomings of existing systems; capabilities required (system performance, logistics and readiness, other characteristicss); program support; force structure; and schedule considerations		

UAV Special Studies Group (SSG)

The JROC established the UAV SSG as its staff-level advisory and action organization for the review of UAV issues. Specific SSG responsibilities include the assessment and evaluation of mission needs and joint UAV requirements and issues, to include Operational Requirements Documents (ORDs), interoperability issues, and programmatic aspects such as performance, cost and schedule status. During FY 1997, the UAV SSG developed and coordinated the UAV mission/payload priority guidance with the Services and CINCs and briefed the JRB, as documented on p. 38.

UAV Program Overview

Predator

The most significant programmatic action of FY 1997 was *Predator's* transition to production within the formal acquisition process. Thirteen months of Integrated Product Team (IPT)-managed post-ACTD transition activities and program/budget trade-offs culminated in Defense Acquisition Board (DAB) approval on 8 August 1997. *Predator* is now an ACAT II program under Air Force milestone review authority. Both ACTD-residual assets (like those operating over Bosnia) and new production systems will be progressively block-upgraded to the required operational configuration.

Outrider

Secondly, the *Outrider* program made sufficient progress during the second half of FY 1997 to justify continuation of its Tactical UAV (TUAV) ACTD and funding for FY 1998. After four months' delay of its first flight to accommodate redesign or reintegration of certain commercial off-the-shelf (COTS) components, as well as resizing the airframe itself to sustain system performance, both the air vehicle and subsystems and the ground control station (GCS) were validated in a succession of flights throughout the summer of 1997. An optimized gasoline engine has been integrated and is in flight test.

HAE

Thirdly, while neither HAE UAV flew in FY 1997, both UAVs' subsystems and sensors were demonstrated successfully. *Global Hawk* taxied for the first time in October 1997, and *DarkStar* AV #2, with redesigned nosewheel and flight control subsystems, plans to taxi in December. Both UAVs are poised to fly during 2Q/FY 1998.

Pioneer

Meanwhile, *Pioneers* operated by both Navy and Marine Corps units demonstrated improved readiness as the result of increased funding for attrition AVs and spares since FY 1995. From beginning to end of FY 1997, Pioneer's readiness grew from 60% to 70%, and its accident rate dropped dramatically from 19 Class A and B mishaps[6] during FY 1996 to 6 mishaps during FY 1997. *Pioneer* passed the 15,000 flight hour mark in July 1997.

Hunter

Finally, the few *Hunters* flying exercise and training support demonstrated current system reliability and sustainability well beyond requirements, thereby validating system and management improvements undertaken before the program's production contract was allowed to expire in early 1996. The small *Hunter* fleet passed 6,600 flight hours in September 1997. Its annual mishap rate has improved from 5.0 per 1,000 flight hours to 0.5 — an order-of-magnitude improvement.

Program	Acq'n Mgr	FY96 Status	FY97 Programmatic Action:
Pioneer	Navy: PEO(CU)	Fielded system	Service life extended through FY03
Hunter	Navy: PEO(CU)	Limited ops/storage	Sustaining 1 system for CONOPS & ops support, plus assets for training
Outrider	Navy: PEO(CU)	ACTD program	ACTD continuing
Predator	Navy: PEO(CU)	Post-ACTD transition	Transitioned to formal acquisition: approved for full production phase
Global Hawk	DARPA	ACTD program	ACTD continuing
DarkStar	DARPA	ACTD program	ACTD continuing

Other key activities within the TUAV program included:

- Establishment of a Heavy Fuel Engine (HFE) program as a development consolidated under the Deputy Under Secretary of Defense (Advanced Technology) (DUSD(AT));
- Successive demonstrations of the Tactical Control System (TCS) to receive sensor data from other UAVs; and
- Contract awards to the *Predator* and *Outrider* primes for TCS integration.

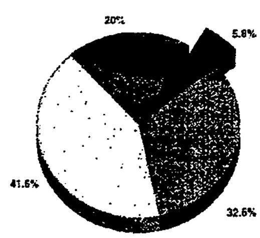
[6] Class A: > $1M loss

Class B: $200K – $1M

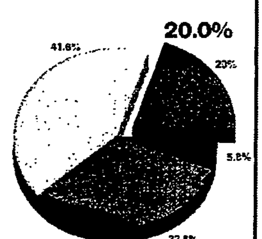
Tactical UAVs

To support: Army battalions, brigades, and light divisions; Marine regiments; and deployed Navy units – Near-real-time reconnaissance, surveillance and target acquisition (RSTA), and battle damage assessment (BDA)

SHARE OF FY 1997 DARP UAV INVESTMENT ($434M)



Pioneer



TUAV

AV	Air Vehicle
COBRA	Coastal Battlefield Reconnaissance and Analysis
COE	Common Operating Environment
CONOPS	Concept of Operations
CSD	Common Systems Environment
DII	Defense Information Infrastructure
EO/IR	Electro-optical/ Infrared
GCS	Ground Control Station
IMINT	Imagery Intelligence
JII	Joint Integration Interface
LPD	Landing Platform Dock
LRIP	Low-rate Initial Production
MIAG	Modular Integrated Avionics Group
O&S	Operations and Support
TCS	Tactical Control System
TUAV	Tactical Unmanned Aerial Vehicle
VTOL	Vertical Takeoff and Landing
UCARS	UAV Common Automated Recovery System

PIONEER & HUNTER

Funding	*Pioneer*	*Hunter*[a]
– FY97	$25.0M	($17.4M)
– FY98	$42.7M	($16.2M)

[a]Army O&M

PROGRAM REQUIREMENTS/OBJECTIVES

- Operate up to 15,000 ft and at ranges ≥ 100 nm
- *Pioneer*: Interim EO/IR IMINT for tactical commanders. Operations to be extended until TUAV is fielded
- *Hunter*: Developed to meet Short Range Requirement for tactical commanders. Now limited fielding to support operations, concept development and follow-on training at Ft. Hood, TX, and initial training at Ft. Huachuca, AZ

ACQUISITION STRATEGY

- *Pioneer*: Contractor: Pioneer UAV, Inc. Sustain nine systems (with attrition AVs and spares); sustain force through FY03, or until TUAV is fielded in quantity. Acquiring 20 new Versatron 12DS EO/IR payloads
- *Hunter*: Contractor: TRW. Seven systems acquired: One operational at Ft. Hood, with additional assets at Ft. Huachuca; remaining assets in storage. O&S focus on reliability improvements and demonstration

MAJOR ACCOMPLISHMENTS

- *Pioneer*: Successful tests of COBRA payload (Nov 96), UCARS ashore (Nov/Dec 96) and at sea (Jan 97), and MIAG (Jul 97). Deployments in Med (VC-6 Det 1 on USS Austin), and to support exercises at NAS Fallon, NV, Yuma, AZ, and others. Passed 15,000 flight hours in Jul 97
- *Hunter*: Provided: key support to Army's Task Force XXI (Mar 97) and to multiple exercises at Ft. Hood; CONOPS development and payload demos at NAS Fallon. Year's performance and reliability far exceeded requirements. Passed 6,600 flight hours in Sep 97

Outrider (TUAV)

Funding	*Outrider*[b]	Other TUAV[c]
– FY97	$46.0M	$19.7M
– FY98	$45.0M	$12.0M

[b]Pending FY98 rescission [c]CSD, TCS, and VTOL

PROGRAM REQUIREMENTS/OBJECTIVES

- Cost: $350,000 @ 33rd AV, $300,000 @ 100th AV, with sensor
- Operate at 200 km range, up to 4 hrs on station
- Compliance w/JII (now DII/COE) standards
- Demonstrate military utility for reconnaissance and surveillance, tactical situational awareness, gun fire support, BDA

ACQUISITION STRATEGY

- Contractor: Alliant Techsystems
- 24-month ACTD: 6 systems and support (now 4). Focus on system integration, shipboard & interoperability demos, exercise support, and logistics definition
- 18-month LRIP option: 6 systems and support (cancelled for FY98). Continued integration, testing, exercise support, and logistics development
- Acquisition strategy under review

MAJOR ACCOMPLISHMENTS

- Modified AV design to meet evolved requirements
- Flight #1: 7 Mar 97; 9 flights through 30 Sep; 17 flights through 16 Nov 97
- Completed four USD(A&T) Program Reviews (Feb, Apr, Jun, and Nov 97)
- GCS demonstrated at Pentagon and elsewhere, Jun 97. Transported to Ft. Hood, TX, in Sep for continuing operational demonstrations and evaluation
- Successfully flight-tested key AV subsystems, 13-foot wing; flown with new engine

Endurance UAVs

To support: Joint Task Force Commanders and Theater/National C2 nodes; goal of sensor-to-shooter interface
– Long-range, long-dwell, near-real-time theater/tactical intelligence via deep penetration/wide-area surveillance

PREDATOR

Funding[d]	*Predator*
– FY97	$141.5M[e]
– FY98	$195.0M

[d]Includes Service funding [e]Includes UCARS integr'n

PROGRAM REQUIREMENTS/OBJECTIVES

- Long-range/dwell, near-real-time tactical intelligence, RSTA, and BDA
- Operate ≥ 15,000 ft and at 400 nm radius
- EO/IR and high-resolution SAR for IMINT

ACQUISITION STRATEGY

- **ACTD:** Contractor: General Atomics – Aeronautical Systems, Inc. 30-month ACTD completed Jun 96. Followed by IPT transition planning to enter formal acquisition process
- **Production:** Contractor: General Atomics. Acquire a total of 12 systems, including residual ACTD assets. Develop baseline configuration and Block I upgrades, and procure/retrofit to Block I configuration. ACAT II program; Air Force has milestone decision authority

MAJOR ACCOMPLISHMENTS

- Initial phase of de-icing tests completed Apr 97
- During post-ACTD transition: JROC approved KPPs and ORD (3 Jul 97); SAF/AQ approved SAMP (21 Jul) and APB (7 Aug); 20-year LCC completed
- At 8 Aug 97 DAB, USD(A&T) approved entry into formal acquisition process as a production program
- Has flown more than 3,700 hours on Bosnia deployments

HAE UAVs

Funding	*Global Hawk*	*DarkStar*	HAE CGS
– FY97	$67.8M	$55.1M	$57.8M
– FY98	$96.0M	$54.6M	$42.1M

PROGRAM REQUIREMENTS/OBJECTIVES

- Military utility w/UFP $10M (FY94 $), AVs #11–20 (average)
- RSTA w/high-altitude, long-range/dwell and wide-area surveillance
- *Global Hawk*: 20 hrs at 65,000 ft and 3,000-nm radius
- *DarkStar*: 8 hrs at 50,000 ft and 500-nm radius

ACQUISITION STRATEGY

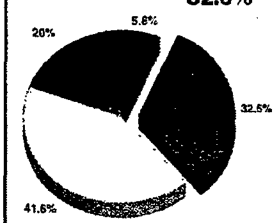
- **ACTD:** Two HAE AVs with CGS to explore military utility and roles/capabilities (USACOM as lead-CINC). DARPA used Other Agreements Authority to streamline contracting and conduct tech demos
- *Global Hawk*: Competitive award to Teledyne Ryan
- *DarkStar*: Sole-source development by Lockheed Martin and Boeing
- **Demo Eval:** Demo military utility (FY 1999-2000)
- **Production:** Decision in FY 2001 (post-ACTD)

MAJOR ACCOMPLISHMENTS

- *Global Hawk*: Rollout 20 Feb 97. INS flight tests (on King Air) in Jul 97; SAR flight tests (on A-3) in Oct. Moved to Edwards FTC, CA, in Aug; taxi tests in Oct. Flight #1 expected 2Q/FY98
- *DarkStar*: EO sensor flight tests (on C-130) May 97. Moved to NASA Dryden FTC in Oct 97; taxi tests in Dec. AV-2 flight #1 expected 2Q/FY98
- **HAE CGS:** LRE moved to Edwards FTC in Sep 97. MCE moved to TRA facility in Oct. Preparing for flight operations

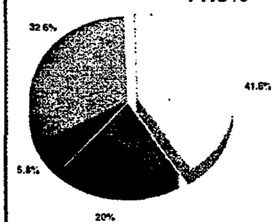
SHARE OF FY 1997 DARP UAV INVESTMENT ($434M)

32.6%



Predator

41.6%



HAE UAVs

ACAT	Acquisition Category
AEW	Airborne Early Warning
APB	Acquisition Program Baseline
BDA	Battle Damage Assessment
C2	Command and Control
CGS	Common Ground Segment
DAB	Defense Acquisition Board
DPE	Data Processing Element
FTC	Flight Test Center
HAE	High Altitude Endurance
INS	Inertial Navigation System
JROC	Joint Requirements Oversight Council
KPP	Key Performance Parameter
LCC	Life-Cycle Costs
LRE	Launch and Recovery Element
MCE	Mission Control Element
ORD	Operational Requirements Document
RCS	Radar Cross-Section
RSTA	Reconnaissance, Surveillance and Target Acquisition
SAMP	Single Acquisition Management Plan
TRA	Teledyne Ryan Aeronautical
UFP	Unit Flyaway Price

	CHARACTERISTICS	Pioneer	Hunter	Tactical UAV Outrider
Operational	**ALTITUDE: Maximum** (km, *ft*) **Operating** (km, *ft*)	4.6 km *15,000 ft* ≤4.6 km *≤15,000 ft*	4.6 km *15,000 ft* ≤4.6 km *≤15,000 ft*	4.6 km *15,000 ft* 1.5 km *5,000 ft*
	ENDURANCE (Max): (hrs)	5 hrs	11.6 hrs	3.6/2.0 hrs @100/200 km
	RADIUS OF ACTION: (km, *nm*)	185 km *100 nm*	267 km *144 nm*	≥200 km *≥108 nm*
	SPEED: Maximum (km/hr, *kts*) **Cruise** (km/hr, *kts*) **Loiter** (km/hr, *kts*)	204 km/hr *110 kts* 120 km/hr *65 kts* 120 km/hr *65 kts*	196 km/hr *106 kts* >165 km/hr *>89 kts* <165 km/hr *<89 kts*	>222 km/hr *>120 kts* 167 km/hr *90 kts* 111-139 km/hr *60-75 kts*
	CLIMB RATE (Max): (m/min, *fpm*)	244 m/min *800 fpm*	232 m/min *761 fpm*	488 m/min *1,600 fpm*
	DEPLOYMENT NEEDS:* *Depends on equipage & duration	Multiple* C-130, C-141, C-17 or C-5 sorties Ship: LPD	Multiple* C-130, C-141, C-17 or C-5 sorties	C-130 (drive on/drive off) Ship: LHA/LHD (roll on/roll off)
Air Vehicle	**PROPULSION: Engine(s)** **– Maker** **– Rating** **– Fuel** **– Capacity** (L, *gal*)	One Recip; 2 cylinders, 2-stroke – Sachs & Fichtel SF 2-350 19.4 kw *26 hp* AVGAS (100 octane) 42/44.6 L *11/12 gal*	Two Recips: 4-stroke – Moto Guzzi (Props: 1 pusher/1 puller) 44.7 kw *60 hp* MOGAS (87 octane) 189 L *50 gal*	One Rotary; pusher prop – UEL AR801R 37.3 kw *50 hp* AVGAS/MOGAS 53 L *14 gal*
	WEIGHT: Empty (kg, *lb*) **Fuel Weight** (kg, *lb*) **Payload** (kg, *lb*) **Max Takeoff** (kg, *lb*)	125/138 kg *276/304 lb* 30/ 32 kg *66/ 70 lb* 34/ 34 kg *75/ 75 lb* 195/205 kg *430/ 452 lb*	544 kg *1,200 lb* 136 kg *300 lb* 91 kg *200 lb* 726 kg *1,600 lb*	195-208 kg *432-458 lb* 36 kg *80 lb* 27 kg *60 lb* >227 kg *>500 lb*
	DIMENSIONS: Wingspan (m, *ft*) **Length** (m, *ft*) **Height** (m, *ft*)	5.2 m *17.0 ft* 4.3 m *14.0 ft* 1.0 m *3.3 ft*	8.9 m *29.2 ft* 7.0 m *23.0 ft* 1.7 m *5.4 ft*	4.0 m *13.0 ft* 3.3 m *10.9 ft* 1.5 m *5.0 ft*
	AVIONICS: Transponder **Navigation**	Mode IIIC IFF GPS	Mode IIIC IFF GPS	Mode IIIC IFF GPS and INS
	LAUNCH & RECOVERY: Land: Ship:	RATO, Rail; Runway, (A-Gear) RATO; Deck w/Net	RATO, Unimproved Runway (200 m)	Unimproved Runway Large-deck Amphibious Ship
	GUIDANCE & CONTROL:	Remote Control/Preprogrammed	Remote Control/Preprogrammed	Prepgmd/Remote Con/Autopilot/Auto
Payload & Links	**SENSOR(S):**	EO or IR (EO and IR with new sensor)	EO and IR	EO and IR (SAR growth)
	DATA LINK(S): Type	Uplink: C-band LOS & UHF LOS Downlink: C-band LOS	C-band LOS	C-band LOS (Digital growth)
	Bandwidth: (Hz)	C-band LOS: 10 Mhz UHF: 600 MHz	20 MHz	20 MHz
	Data Rate: **– Analog** (Hz) **– Digital** (bps)	C-band LOS: 10 MHz UHF: 7.317 kbps	20 MHz	20 MHz with embedded 19.2 kbps C2 and telemetry data stream
	C2 LINK(S):	Through Data Links	Through Data Link	Through Data Link
System & Support	**SYSTEM COMPOSITION:**	5 AVs, 9 payloads (5 day cameras, 4 FLIRs), 1 GCS, 1 PCS, 1–4 RRSs, 1 TML (USMC units only)	8 AVs, 8 MOSPs, 4 ADRs, 4 RVTs, 3 GCSs/MPSs, 2 GDTs, 1 LRS, 1 MMF	4 AVs, GCSs, GDTs, 1 RVT, 1 MMF (per 3 systems), LRE, GSE
	PRIME/KEY CONTRACTOR(S):	Pioneer UAV, Inc.	TRW Avionics & Surveillance Group	Alliant Techsystems
	MAJOR SUBCONTRACTORS: – Air Vehicle, Propulsion, Avionics, Payloads, Information Processing, Communications, Ground and Support Systems	AAI Corp; Computer Instrument Corp; General Svcs Engrg; Humphrey; Israel Aircraft Industries (IAI); Sachs; Trimble Navigation	Alaska Ind.; Burtek; Consolidated Ind.; Fiber Com; Gichner; IAI/Malat; IAI/Elta; IAI/Malat/Tamam; ITT/Cannon; Lopardo: Mechtronics; Moto Guzzi	BMS; Cirrus Design; CDL; FLIR Syste IAI Tamam; IntegriNautics; Lockheed Martin; Mission Technologies; Phototele TI; Rockwell Collins; SwRi; Stratos Grc UAV Engines Ltd

Column Notes: *AV weights: Option 2 / Option 2+*



Tier II, MAE UAV ***Predator***	Tier II+, CONV HAE UAV ***Global Hawk***	Tier III–, LO HAE UAV ***DarkStar***
5 km *25,000 ft*	19.8 km *65,000 ft*	15.2 km *50,000 ft*
5 km *15,000 ft*	15.2–19.8 km *50,000–65,000 ft*	15.2 km *50,000 ft*
5 hrs	38 hrs (20 hrs at 5,556 km/*3,000 nm*)	12 hrs (8 at 926 km/*500 nm**)
km *400 nm*	5,556 km *3,000 nm*	>926 km *>500 nm*
-215 km/hr *110-115 kts*	>639 km/hr *>345 kts*	556 km/hr *300 kts*
-130 km/hr *65- 70 kts*	639 km/hr *345 kts*	556 km/hr *300 kts*
-120 km/hr *60- 65 kts*	630 km/hr *340 kts*	241 km/hr *130 kts*
m/min *450 fpm* (912 eng) m/min *800 fpm* (914 eng)	1,036 m/min *3,400 fpm*	610 m/min *2,000 fpm*
tiple* C-130 sorties	AV: Self-Deployable GS: Multiple* C-141, C-17 or C-5 sorties	Multiple* C-141, C-17 or C-5 sorties
Fuel-Injected Recip; 4-stroke otax 912/Rotax 914	One Turbofan – Allison AE3007H	One Turbofan – Williams FJ 44-1A
.4/75.8 kw *85/105 hp*	32 kN *7,050 lb static thrust*	8.45 kN *1,900 lb static thrust*
GAS (100 Octane)	Heavy Fuel (JP-8)	Heavy Fuel (JP-8)
09 L *108 gal*	8,176 L *2,160 gal*	1,575 L *416 gal*
44 kg *1,200 lb*	4,055 kg *8,940 lb*	1,978 kg *4,360 lb*
00 kg *660 lb*	6,668 kg *14,700 lb*	1,470 kg *3,240 lb*
04 kg *450 lb*	889 kg *1,960 lb*	454 kg *1,000 lb*
34 kg *2,500 lb*	11,612 kg *25,600 lb*	3,901 kg *8,600 lb*
4.8 m *48.7 ft*	35.4 m *116.2 ft*	21.0 m *69 ft*
3.1 m *26.7 ft*	13.5 m *44.4 ft*	4.6 m *15 ft*
2.2 m *7.3 ft*	4.6 m *15.2 ft*	1.5 m *5 ft*
de IIIC IFF S and INS	Mode I / II / IIIC / IV IFF GPS and INS	Mode IIIC IFF GPS and INS
way (760 m/*2,500 ft*)	Runway (1,524 m/*5,000 ft*)	Runway (<1,219 m/*<4,000 ft*)
pgmd/Remote Control/Autonomous	Preprogrammed/Autonomous	Preprogrammed/Autonomous
IR, and SAR	EO, IR, and SAR	EO or SAR
and LOS; (growth to Ku-band TCDL); band SATCOM	UHF LOS and SATCOM; X-band CDL LOS; Ku-band SATCOM	UHF LOS and SATCOM; X-band CDL LOS; Ku-band SATCOM
and LOS: 20 MHz band SATCOM: RL/CL: 5/9 MHz	UHF LOS/SATCOM: 25/25 kHz X-CDL LOS: RL/CL: 137/64 MHz Ku-SATCOM: RL/CL: 3-69/0.26 MHz	UHF LOS/SATCOM: 9.6/25 kHz DAMA X-CDL LOS: RL/CL: 137/64 MHz Ku-SATCOM: RL/CL: 26/(N/A) MHz
and LOS: 20 MHz band SATCOM: RL: 1.544 Mbps CL: 64 kpbs	UHF LOS/SATCOM: 9.6/9.6 kbps X-CDL LOS: RL: 137 Mbps (48 used) CL: 200 kbps Ku-SATCOM: RL: 1.5-48 Mbps CL: 200 kbps	UHF LOS/SATCOM: 4.8/1.2 & 2.4 kbps* X-CDL LOS: RL: 137 Mbps (84 used) CL: 200 kbps Ku-SATCOM: RL: 1.54 Mbps CL: (N/A)
ough Data Links	Through Data Links	Through UHF LOS, UHF SATCOM, or CDL LOS
/s, 1 GCS, 1 Trojan Spirit II semination System, GSE	AVs (TBD); HAE CGS	AVs (TBD); HAE CGS
eral Atomics-Aeronautical Systems	Teledyne Ryan Aeronautical	Lockheed Martin Skunk Works/ Boeing Military Aircraft Division
ing Defense & Space (DEMPC); Litton S/GPS); L3 Com (Ku-band SATCOM); gnavox/ Carlyle Gp; Northrop Grumman R); Rotax Cp (engine); Trimble (GPS): satron Cp (EO/IR)	Allison Engine/Rolls Royce; Aurora Flight Sciences; Boeing Rockwell; GDE Systems/Tracor; Héroux; Hughes Aircraft; L3 Com; Menasco; Raytheon E-Systems	ABS Cp; Advanced Composites; Aydin Vector; CI Fiberite; Hexcel; Honeywell Avionics; Litton G&C; L3 Com; Recon/ Optical; Rockwell Collins; Rosemount Aerospace; Northrop Grumman, Williams International

Developmental estimates

*1.2 kbps C2 (shared by 3 AVs); 2.5 kbps ATC (per AV)

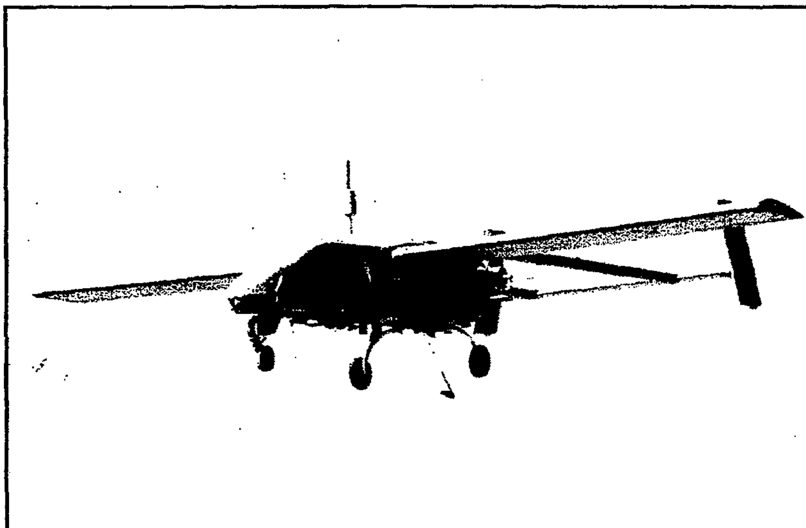
Legend:

ADR	Air Data Relay
A-Gear	Arresting Gear
ATC	Air Traffic Control
AV	Air Vehicle
AVGAS	Aviation Gasoline
C2	Comand and Control
CDL	Common Data Link
CGS	Common Ground Segment
CL	Command Link
DAMA	Demand Assigned Multiple Access
DEMPC	Data Exploitation, Mission Planning and Communications
EO	Electro-Optical
FLIR	Forward-Looking Infrared
GCS	Ground Control Station
GDT	Ground Data Terminal
GPS	Global Positioning System
GSE	Ground Support Equipment
HAE	High Altitude Endurance
IFF	Identification, Friend or Foe
INS	Inertial Navigation System
IR	Infrared
JP	Jet Petroleum
LHA	Landing Helicopter Amphibious
LHD	Landing Helicopter Dock
LOS	Line of Sight
LPD	Landing Platform Dock
LRE	Launch & Recovery Equipment
LRS	Launch & Recovery System
MAE	Medium Altitude Endurance
MMF	Mobile Maintenance Facility
MOGAS	Mobility Gasoline
MOSP	Multi-mission Optronic Stabilized Payload
MPS	Mission Planning Station
PCS	Portable Control Station
RATO	Rocket-Assisted Takeoff
RL	Return Link
RRS	Remote Receiving Station
RVT	Remote Video Terminal
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications (Military)
TCDL	Tactical Common Data Link
TML	Truck-Mounted Launcher
UHF	Ultra High Frequency

RQ-2A Pioneer

General

Pioneer was procured starting in 1985 as an interim UAV capability to provide imagery intelligence (IMINT) for tactical commanders on land and at sea. We continue to operate nine systems in the active force: the Navy and Marine Corps operate five and two systems, respectively, and two are assigned to Ft. Huachuca, AZ. In 12 years, *Pioneer* has flown nearly 16,000 hours. During Persian Gulf operations in 1990 – 91, it flew over 300 combat operations in support of the ground forces. Since 1994, it has flown missions over Haiti, Somalia, and Bosnia. The two Bosnia deployments (one afloat, one ashore) involved support of NATO peacekeeping forces, monitoring population centers, and searching for terrorists. Prime contractor is Pioneer UAV, Inc., Hunt Valley, MD.



Subsystems

- 5 Air Vehicles
- 1 Ground Control Station
- 1 Portable Control Station
- 4 Remote Receiving Stations (max)
- 1 Truck-Mounted Launcher

Key Operational Factors

Sensors:	EO or IR (EO and IR with new sensor)
Deployment:	Multiple[b] C-130/C-141/C-17/C-5 sorties; also shipboard
Radius:	185 km (100 nm)
Endurance:	5 hrs
Ceiling:	4.6 km (15,000 ft)
Cruise Speed:	120 km/hr (65 kts)

[b]Depends on equipage and duration

Flight Data[a]	Bosnia	FY97	Total to Date
• Flights / Hours	39 / 95	1,089 / 2,077	>5,100 / 15,815

[a]As of 30 Sep 97

Funding (Then-Year $M):	FY97	FY98
• Weapons Procurement, Navy		42.7
• Other Procurement, Navy	25.0	

FY 1997 Activities

With the Navy's decision to extend *Pioneer's* operational life to FY 2003 or until TUAV systems are fielded in quantity, the Service has continued to invest in spares and readiness improvements, to include subsystem upgrades.

Integration and testing of the UAV Common Automated Recovery System (UCARS) and Modular Integrated Avionics Group (MIAG) were completed in FY 1997. UCARS will improve UAV recovery operations, while MIAG will improve avionics functions for less weight and cost (see p. 36). Procurement of production UCARS and MIAG units will begin in FY 1998, along with a new buy of 15 AVs; fleet retrofits will be made thereafter.

PEO(CU) is currently acquiring two prototype and 20 production versions of a new EO/IR payload, which will improve performance and reliability at less weight. It is a modified Versatron 12DS (dual sensor: TV and forward-looking infrared [FLIR]), which will allow autotrack capability and on-the-fly selection of day or night sensors. The contract includes two options for 20 additional payloads, each.

A competition is underway for an alternate engine source to provide replacements for the Sachs SF2-350 engine, which is out of production. The intent is to increase engine reliability and power while minimizing impacts to AV configuration. A contract award is planned for December 1997.

These new subsystems will enhance *Pioneer's* contributions to naval and joint operations into the 21st century.

The fleet passed the 15,000-hour flying mark in July 1997. VC-6 was the first unit to exceed 1,000 hours in a single year, with 1,161.5 hours during FY 1997. NAMTRAGRUDET also broke its annual flight hour record with 577.9 hours.

Hunter

General

The *Hunter* UAV was originally developed to provide both ground and maritime forces with near-real-time IMINT within a 200-km direct radius of action, extendible to 300+ km by using another *Hunter* as an airborne relay. *Hunter* can operate from runways or unimproved air strips (200m x 75m and RATO launch) to support ground tactical force commanders. System production stopped in FY 1996 with delivery of the initial 7 systems; one full system supports the 15th Military Intelligence Battalion (MI Bn) at Ft. Hood, TX, and other assets support the Joint UAV Training Center at Ft. Huachuca, AZ. Prime contractor is TRW, San Diego, CA.

[During TF XXI,] Hunter demonstrated hands down the value of a tactical UAV under the control of the brigade commander.

GEN Hartzog
CG, TRADOC
9 April 1997

Subsystems

- 8 Air Vehicles
- 4 Remote Video Terminals
- 3 Ground Control/Mission Planning Stations
- 2 Ground Data Terminals
- 1 Launch and Recovery System
- 1 Mobile Maintenance Facility

Key Operational Factors

Sensors:	EO and IR
Radius:	267 km (144 nm)
Endurance:	11.6 hrs
Max Altitude:	4.6 km (15,000 ft)
Cruise Speed:	>165 km/hr (>89 kts)

Funding (Then-Year $M):	FY97	FY98
• Ops & Maintenance (Army)	17.4	16.2

Flight Data*	TF XXI AWE	FY97	Total
• Flights / Hours	56 / 282	558 / 1,973	2,152 / 6,607

*As of 30 Sep 97

FY 1997 Activities

Hunter continued to support Army and joint exercises and training (see pp. 7–10). In addition, a 4-AV "*Hunter* Lite" demo system, operated by contractor personnel, supports payload experiments and other exercises. Since resuming flight in December 1995, system performance and reliability have far exceeded original requirements. It has flown over 3,100 hours and its mishap rate has improved from 5.0 per 1,000 flight hours to 0.5 — a factor of ten.

Its operational demonstrations of the value of tactical UAVs have elicited strong praise from the user community. During TF XXI alone, for example, *Hunters* not only flew brigade support missions (as the TUAV surrogate), but also division support missions on request. Some missions combined Joint STARS' "big picture" surveillance and alerting with the UAV's capability to validate information and see the detail. *Hunters* provided adjustment of artillery fire, precise targeting and near-real-time BDA, while maintaining a readiness rate of above 90%. Their ability to keep the enemy force under stress helped to disrupt its operations while enabling the friendly force to accelerate its targeting and decision-making processes.

Other *Hunter* activities included:

- ❒ Support for multiple exercises at Fort Hood, TX, as contributions to evolving concepts and doctrine;
- ❒ The loan of four AVs to the Navy for CONOPS development and payload demonstrations at NAS Fallon, NV;
- ❒ Target acquisition for an Army Tactical Missile System (ATACMS) and Navy Tomahawk Operational Test launches;
- ❒ Laser designation for several Kiowa/Hellfire live missile shots (all direct hits); and, at NAS Fallon, designation for three Paveway munitions (also all hits); and
- ❒ Communications relay for units operating beyond line-of-sight (BLOS).

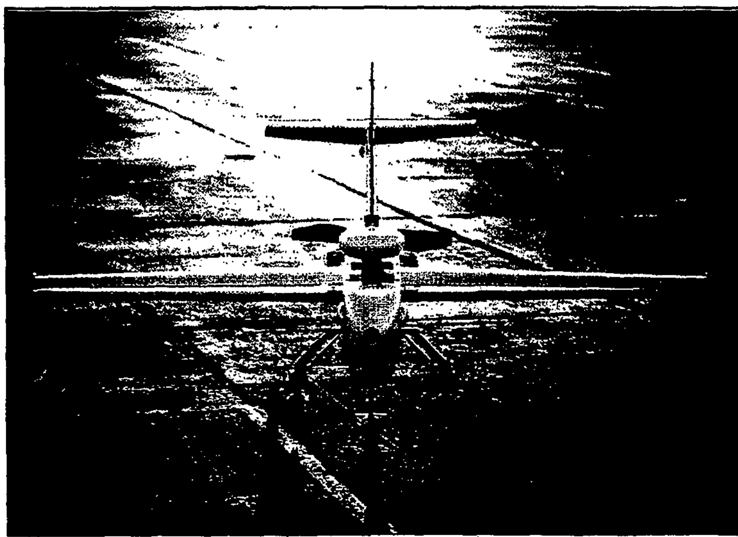
"Alpha Company and the Hunter system are the cream of the crop"

SecDef Cohen, speaking to 15 MI Bn soldiers at TF XXI AWE, 19 March 1997.

Outrider

General

The *Outrider* Tactical UAV (TUAV) is an Advanced Concept Technology Demonstration (ACTD) program to demonstrate a dedicated UAV reconnaissance system for Army brigade, Marine Air-Ground Task Force (MAGTF) and Navy commanders. To meet joint requirements, the TUAV needs to deliver timely and accurate reconnaissance, surveillance and target information at ranges up to 200 km and with on-station endurance up to 4 hours. *Outrider* is designed for both land-based and shipborne operations, with an automatic takeoff and landing capability for short, unimproved ground surfaces or large-deck amphibious ships. The ACTD involves a two-year cost-plus contract with a low-rate initial production (LRIP) option. Prime contractor is Alliant Techsystems, Hopkins, MN.



Subsystems

4 Air Vehicles
4 Modular Mission Payloads
2 Ground Control Stations and Data Terminals
1 Remote Video Terminal
Launch & Recovery: Auto Takeoff and Landing
Ground Support Equipment (incl. 2 HMMWVs/2 Trailers)

Key Operational Factors

Sensors:	EO and IR (SAR growth)
Deployment:	C-130/C-141C/C-17/C-5 sortie(s); also shipboard
Radius:	200 km (108 nm)
Endurance:	3.6/2.0 hrs on-station @ 100/200 km
Max Altitude:	4.6 km (15,000 ft)
Cruise Speed:	167 km/hr (90 kts)

Flight Data[a]	FY97	Total to Date
• Flights / Hours	9 / 2.3	9 / 2.3

[a]As of 30 Sep 97

Funding (TUAV) ($M):	FY97	FY98
• RDT&E, Def-wide – *Outrider*	46.0[b]	
• RDT&E, Army – *Outrider*		45.0

[b]Pending FY 1998 rescission

FY 1997 Activities

The past year was characterized by challenges for this demonstration program. Integration of nondevelopmental and commercial off-the-shelf (NDI and COTS) items to accommodate desired military performance parameters[7] required additional system engineering, integration, and trade-offs. These changes extended the ACTD's internal schedule by several months and incurred both Defense Department and Congressional concern. As a result of cost increases, four ACTD systems will be delivered in FY1998, vice the six originally planned.

A series of USD(A&T)-chaired program reviews, held in February, April, June and November 1997, provided oversight and direction to resolve the program's issues. Directed activities included pursuit of UCARS for the TUAV, Service study of alternative acquisition strategies to meet land and maritime TUAV requirements, and a survey of industry to assure their feasibility. Major system changes include:

- Rebaselining the air vehicle with a 13-ft wing and 11-ft fuselage;
- Redesigning the landing gear and air data terminal;
- Incorporating a new alternator and servo; and
- Incorporating a new gasoline engine to complete the ACTD, instead of the optional heavy fuel engine (HFE).

The direction to replace *Outrider's* initial, contractor-proposed HFE by a rotary gasoline engine both helped to reclaim flight profile performance losses and recognized that HFE technology was not yet available for application to small UAVs.[8] Concurrently, a series of flights

validated key subsystems while program and performance trades were examined. Joint Staff, Army, Navy and Marine spokesmen all agreed that the TUAV is likely to meet their near-term requirements, although an alternative approach may be necessary to meet the Navy's longer-range sea-based on-station requirement. As a result, DoD strongly supported continuation of the ACTD and the Congress, while rescinding some FY 1997 funds and denying FY 1998 funds for the ACTD's LRIP option, has funded its completion.

During the past year, the C-band data link and EO/IR payload subsystems were validated aboard a helicopter, to include confirmation of data link capability beyond 200 km. The GCS, which enables mission planning, in-flight control of the air vehicle and sensor, and information product dissemination to users in the field, is undergoing acceptance tests. The GCS has participated in the Army's Force Exercise XXI and AWE at Ft. Hood, TX, during which tactical intelligence was provided through MUSE, the synthetic video simulation system. *Outrider's* GCS served a critical role by providing the commander with near-real-time information. It has demonstrated full compatibility with the Army's All-Source Analysis System (ASAS) and, with no downtime thus far, has demonstrated its reliability.

"For the past two years, the JROC has supported the development of a tactical UAV as its highest UAV priority...."

Gen Ralston, USAF
JROC Chairman
Letter to Congress
14 July 1997

Recent Activity and Near-Term Plans

Flight test of the air vehicle's ground and flight handling subsystems continues. The contractor is refining the propulsion, electrical power and landing gear subsystems, validating basic operating procedures, and integrating other design changes.

On 4 November, *Outrider* flew its 13th flight, the first with the new 801R rotary gasoline engine, built by UAV Engines Ltd (UEL), UK. Throughout this flight, it also used the Stability Augmentation System (SAS) from launch through recovery. By 16 November, *Outrider* had flown another four times, for a total of 17 flights and 5.7 hours. Full autopilot functionality evaluation begins in 1Q/FY 1998. Delivery of the first TUAV system for Military Utility Assessment will be made to Ft. Hood, TX, in 2Q/FY 1998.

Program decisions resulting from separate JROC and Acting USD(A&T) reviews on 3 November 1997 included:

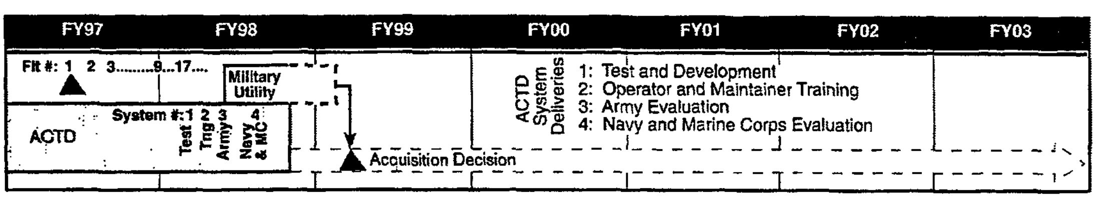
- Reiteration by the JROC that TUAV is their number one UAV priority; and
- USD(A&T) continuation of the ACTD, and direction for another program update by 1 December with focus on system performance with the UEL gasoline engine, AV delivery status, and continuing analysis of acquisition alternatives.

The Services are currently developing acquisition approaches that will conform with the Congress's guidance and terms of the FY 1998 Budget, in preparation for the December 1997 USD(A&T) review.

"I am encouraged by the significant progress of the program over recent months ... We believe that the ACTD offers us the best and most prudent course of action at this time."

R. Noel Longuemare
Acting USD(A&T)
Letter to Congress
5 September 1997

Schedule



[7] Per 21 December 1995 Acquisition Decision Memorandum, which established the TUAV ACTD, the sole formal requirements dealt with meeting joint integration interface standards (now Defense Information Infrastructure/Common Operating Environment standards) and projected unit costs for single air vehicle and sensor: $350,000 for #33, and $300,000 for #100. The TUAV was to "come as close as possible" to meeting other basic requirements.

[8] Instead, a consolidated HFE development program under the DUSD(AT) was established to mature this technology independently of specific aircraft programs (see p. 37).

Tactical Control System (TCS)

"TCS is an essential building block for the long-term success of UAV technology. It combines the necessary requisites of affordability, mission effectiveness, and easy integration into all services' existing and planned C4I systems. It will be a key provider of joint interoperability for the United States and Allies."

RADM Barton Strong PEO(CU)

General

TCS is a DoD program to provide joint warfighters with a surface command, control, communications and data dissemination system for UAVs. It has made considerable progress over the past year and demonstrated initial functionality and versatility in a variety of land- and sea-based exercises.

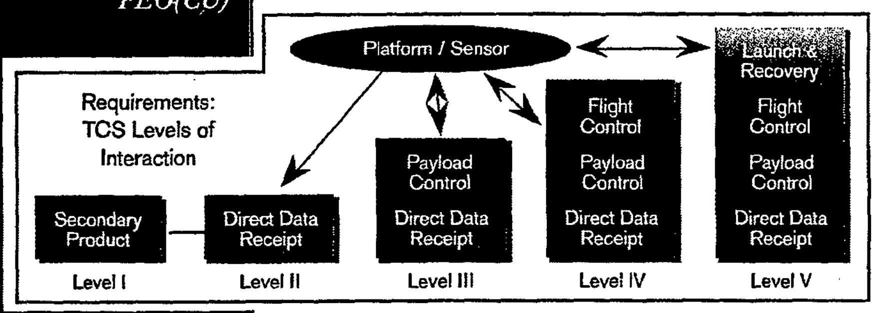
TCS is composed primarily of software, but also related hardware and additional ground/ship support equipment, to enable:

- Software interoperability on host-Service computer platforms;
- Five levels of scalable interaction, from passive imagery/data receipt to full AV control (see figure below); and
- Rapid imagery dissemination to tactical users through a variety of C4I system interfaces.

It is being designed as an open architecture system to facilitate future hardware and software enhancements and will comply with:

- ASD(C3I)'s Joint Technical Architecture;
- Distributed Common Ground System (DCGS) standards of the Common Imagery Ground/Surface System (CIGSS); and
- The Defense Information Infrastructure/ Common Operating Environment (DII/ COE).

Initially, TCS will be integrated with *Outrider* and *Predator* and will incorporate the five levels of interaction. Integration planning has also been initiated for *Pioneer* and *Hunter*. Subsequently, receipt of payload information from the HAE UAVs will enable TCS's rapid dissemination of their imagery and data to selected C4I systems. TCS thus provides a migration path to interoperable UAV employment with a common interface to the C4I infrastructure.



NATO is interested in TCS's range of flexible options for Alliance operations. The NATO Industry Advisory Group's Project Group 35 (NIAG PG/35) has initiated a study to define a common, interoperable NATO UAV GCS architecture. In September 1998, TCS will take part in an interoperability demonstration with a German UAV.

FY 1997 Activities

JROC Activity

The JROC fully supports TCS as critical to the successful development and employment of UAV systems (see p. 18). In JROCM 173-96, which updated UAV priorities, the JROC emphasized the need for commonality and interoperability in the control of UAVs and dissemination of their data .

Programmatic Activities

In January 1997, the Expanded Defense Resources Board (EDRB) approved $63 million in additional funding for FY 1998 – 03 to accelerate the program. TCS is being developed as a three-phase effort (see table above-right).[9]

Φ	Focus	TCS Units	Activities / Objectives
I	Program definition and risk reduction	3 Protypes	Software dev't; early ops assessments; MS II; integration contract
II	Engineering & Manufacturing Development (EMD)	6 LRIPs	Block 0 system test & integration; Block 1 design reviews; MS III
III	Production and Fielding	≈ 200 (projected)	Production; IOC; Block & P3I upgrades; ops testing; FOC; O&S

Phase I is an incremental build to demonstrate increasing TCS functionality from passive receipt of data to payload and multi-UAV control. Its three fieldable prototypes represent the various TCS operational environments: sea-based, HMMWV-shelterized, and in a Tactical

[9] The Block 0 TCS will demonstrate the five levels of interaction by the end of Phase I.

Operations Center (TOC). **Phase II** will continue demonstrations and acquire six low-rate initial production (LRIP) systems for an Initial Operational Test and Evaluation (IOT&E) program. **Phase III** will include production, support, preplanned product improvements (P3I), and incorporation of additional C4I interfaces.

In March 1997, contracts were awarded to General Atomics and Alliant Techsystems for TCS integration into *Predator* and *Outrider*, respectively. In November, Logicon was selected to provide an off-the-shelf TCS Mission Planner. An RFP for a TCS Systems Integrator is planned for release to industry in 2Q/FY 1998, with contract award in 4Q/FY 1998.

In coordination with DARO, the Assistant Secretary of the Navy (Research, Development and Acquisition) (ASN(RD&A)) formed an Acquisition Coordination Team (ACT) to support the TCS program after designating it an ACAT II program on 12 September 1997.

Funding (Then-Year $M):	FY97	FY98
• RDT&E, Defense-wide	6.3	42.5[a]

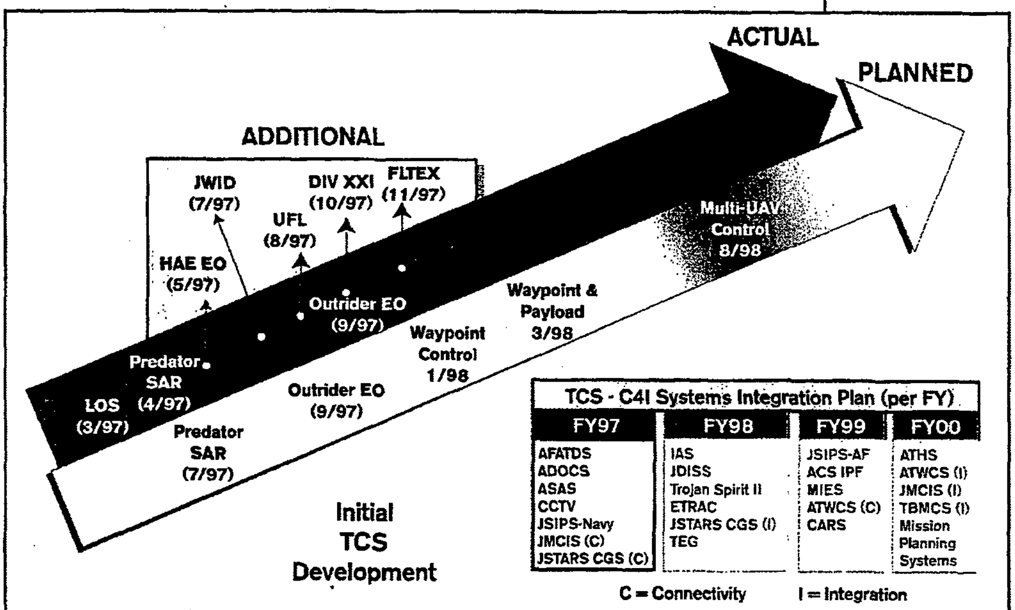
[a]Includes Congressional addition for Predator AV and GCS

"TCS, when fielded, will be a valuable tool in the joint warfighters' range of capabilities."

U.S. Atlantic Command, Norfolk NAS, VA

Demonstrations

A TCS prototype took part in the Army's TF XXI AWE in March 1997 (see p. 8). During April and May lab demonstrations, TCS showed it could receive *Predator* SAR and *DarkStar* EO data, respectively. It hosted demonstrations at several locations, including the Pentagon. During Joint Warrior Interoperability Demonstration 1997 (JWID-97) in June, it was used in a sensor-to-shooter interoperability demonstration aboard the USS Stennis. In mid-summer, it performed shipboard data receipt and dissemination of simulated UAV payload imagery generated by MUSE.[10] In August, TCS/MUSE supported the Army's Exercise Ulchi Focus Lens 97 (see p. 9).



TCS - C4I Systems Integration Plan (per FY)			
FY97	FY98	FY99	FY00
AFATDS	IAS	JSIPS-AF	ATHS
ADOCS	JDISS	ACS IPF	ATWCS (I)
ASAS	Trojan Spirit II	MIES	JMCIS (I)
CCTV	ETRAC	ATWCS (C)	TBMCS (I)
JSIPS-Navy	JSTARS CGS (I)	CARS	Mission Planning Systems
JMCIS (C)	TEG		
JSTARS CGS (C)			

C = Connectivity I = Integration

TCS's use during exercises has shown operators at all levels what it can do and what is planned for the future. In addition, the exercises demonstrated successful data distribution to various C4I nodes and also provided valuable feedback to developers.

[10] Multiple UAV Simulation Environment (see p. 39).

Near-Term Plans

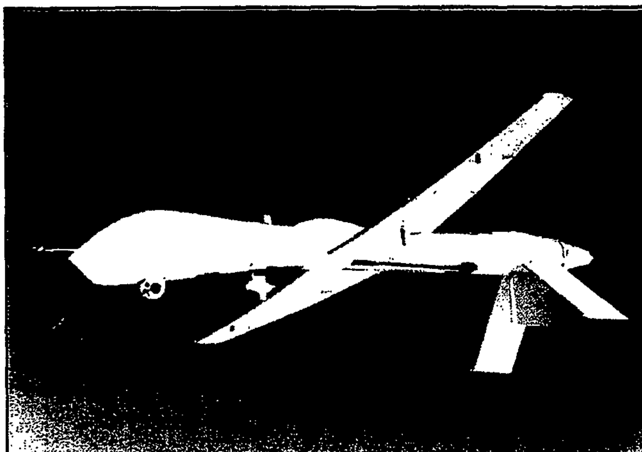
With enactment of its FY 1998 budget, the TCS Program Office will:

- ❐ Continue functionality demonstrations of land- and sea-based TCS units;
- ❐ Procure a *Predator* AV and GCS with additional funds provided (see p. 3);
- ❐ Select a TCS/LRIP System Test and Integration contractor;
- ❐ Downselect for mission and payload planning application;
- ❐ Complete the TCS TEMP;
- ❐ Coordinate TCS incorporation into the *Pioneer* and *Hunter* programs;
- ❐ Participate in joint warfighting and Service experiments and exercises, to include *Predator* and *Outrider* demonstrations; and
- ❐ Engage in multi-UAV simulation efforts.

RQ-1A Predator

General

Predator, formerly known as the Medium Altitude Endurance (MAE) or Tier II UAV, is a derivative of the *Gnat 750* (Tier I) UAV. The system provides long-range, long-dwell, near-real-time imagery intelligence (IMINT) to satisfy reconnaissance, surveillance and target acquisition (RSTA) mission requirements. The air vehicle carries both EO/IR and SAR sensors which, with a Ku-band satellite communication (SATCOM) links, enable the system to acquire and pass highly accurate imagery to ground stations for theater-wide use by tactical commanders. *Predator* redeployed to Taszar, Hungary, in March 1996 to support NATO operations in Bosnia and has been there ever since. On 30 June 1996, *Predator* completed its 30-month ACTD program and in August 1997 transitioned to a production program in the formal acquisition arena. Prime contractor is General Atomics – Aeronautical Systems, Inc., San Diego, CA.



Subsystems

4 Air Vehicles (per production system)
1 Ground Control Station
1 Trojan Spirit II Dissemination System
Ground Support Equipment

Key Operational Factors

Sensors:	EO, IR and SAR
Deployment:	Multiple[b] C-130 sorties
Radius:	740 km (400 nm)
Endurance:	≈35 hrs
Max Altitude:	7.6 km (25,000 ft)
Cruise Speed:	120-130 km/hr (65-70 kts)

[b]Depends on equipage and duration

Flight Data[a]	Bosnia	FY97	Total to Date
• Flights / Hours	607 / 3,742	595 / 2,613	1,504 / 6,756

[a]As of 30 Sep 97

Funding (Then-Year $M):	FY97	FY98
• RDT&E (Defense-wide)	7.8	
• RDT&E (AF)		15.0
• A/C Procurement (AF)	107.8	141.5
• Other Procurement (AF)	2.9	
• Other Procurement (Navy)	5.6	
• Military Construction (AF)	4.7	
• Ops & Maintenance (AF)	5.5	18.6
• Military Personnel (AF)	7.3	20.0

One of the big reasons that there's peace in Bosnia today is because of the technology like this, that ferrets out the weapons and lets the other side know that we know where they are ...

Randy "Duke" Cunningham
U.S. Rep, CA
51st District

FY 1997 Activities

Predator met two challenges successfully this past year. First, residual ACTD assets continued full support of NATO operations in Bosnia (see pp. 4-5), which precluded their participation in most other activities at home. Secondly, the program transitioned to production, the first ACTD to enter the formal acquisition process.

On 2 January 1997, the USD(A&T) authorized limited procurement by the Air Force (through the Navy's PEO(CU)) to sustain the post-ACTD residual assets, to include:

- One AV to replace one that had crashed;
- Five additional AVs and three Trojan Spirits to complete the existing systems (as redefined); and
- Their necessary support.

Thirteen months of transition activities focused on resolving key issues with respect to requirements, acquisition approach, force size and funding, reliability and support, and configuration upgrades. There were no short cuts to *Predator's* production approval. System trades and follow-on developments and tests were incorporated into the program to meet both joint and lead-Service requirements for system performance and sustainability. Other activities included a life-cycle cost (LCC) analysis,[11] and a Lease vs. Buy study (with the recommendation to "buy"). Further, lessons learned during *Predator's* ACTD and transition have been documented for other ACTD programs (see pp. 16-17).

On 8 August 1997, the Defense Acquisition Board approved *Predator's* entry into the production phase of the acquisition process, designated the program as Acquisition

[11] 12-System LCC:
(Base-year FY 1996 $M)
• RDT&E 213
• Production 512
• O&S, etc. 697
– Total: 1,422

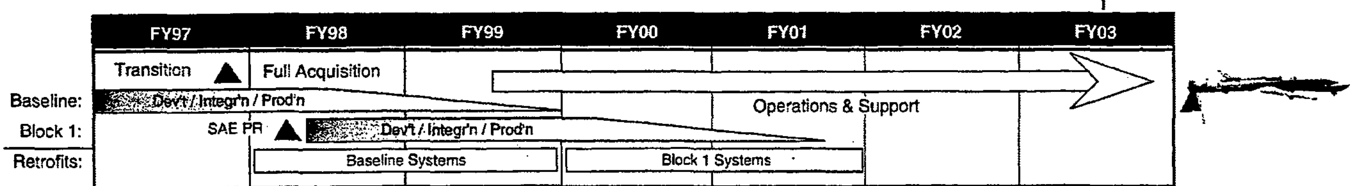
Category II (ACAT II), and delegated milestone decision authority (MDA) to the Air Force.[12]

The approved *Predator* program includes a total of 12 systems, with a block-upgrade program to phase in additional P3I capabilities. The Air Force has initiated a streamlined acquisition process by eliminating as much government furnished equipment (GFE) and government contracting as possible, and by giving total system performance responsibility (TSPR) to General Atomics. The Service plans a program review (PR) to initiate production of systems #9 and #10 early in FY 1998; procurement of systems #11 and #12 are planned for FY 1999 and 2000, respectively. With Congressional approval of the FY 1998 budget request, the program is fully funded for FY 1998, and resources are fully programmed for the out-years.

Documentation	Authority	Approved
Operational Assessment (in ACTD)	ACC	24 Jun 96
Key Performance Parameters (KPPs)	JROC	3 Jul 97
Operational Requirements Document (ORD)	JROC	3 Jul 97
Single Acquisition Management Plan (SAMP)	SAF/AQ	21 Jul 97
Acquisition Program Baseline (APB)	SAF/AQ	7 Aug 97
Test and Evaluation Master Plan (TEMP)	DOT&E	(1Q/FY98)

[12] USD(A&T) *Predator* UAV Acquisition Decision Memorandum, August 18, 1997.

Schedule



Configuration Management

Another noteworthy outcome of Predator's transition planning is its evolution to a more capable system much earlier in the acquisition process. A year ago, just three features were considered essential for a production baseline configuration, though many others were identified as P3I candidates. Now, seven features will be in or retrofitted to the Baseline configuration, with an additional five incorporated into the Block I acquisition. Although funding was available for 13 systems, the Air Force chose to fund 12 better-quality systems, with progressive improvements in sustainability, from the outset. Block I capabilities are planned for first delivery with system #10 in FY 2000.

Configuration Feature	Remarks
Baseline (Post-ACTD):	
• De-ice Systems	– Required for all-weather operation
• Rotax 914 Engine	– Improved performance (over 912)
• Air Traffic Control – Voice	– For communications with ATC
• Mode IV IFF	– Positive airborne control requirement
• Relief on Station (ROS)	– Two UAVs controlled from one GCS
• GCS Repackaging	– Improved equipment for fielding
• R&M Improvements (I)	– To meet ORD requirements
Block 1 (Production)	
• GCS Comms / Red/Black	– Secure and unsecure communications
• Tactical Control System	– For interoperability with C4I
• AF Mission Support System (AFMSS) Interface	– Compatibility with another Air Force ground station
• R&M Improvements (II)	– To meet ORD requirements
• UCARS	– To enhance operational safety

Note:

FY 1996 transition planning envisioned an LRIP program prior to full production, with only a few of these features planned as P3I items.

Predator and Maritime Operations

The Congressionally directed *Predator* Marinization Feasibility Study was reported to the Congress in January 1997. The study concluded that fully marinizing *Predator* for launch and recovery aboard "large deck" naval platforms, though feasible, would incur significant modifications, testing, and costs. Accordingly, the Navy decided not to develop *Predator* on-board capabilities, but to continue demonstrating MAE UAV technologies from shore-based locations. This will augment its evolving concept for UAV support for carrier battle groups and Marine Expeditionary Forces to the extent of their weapon ranges and aircraft capabilities.

RQ-4A *Global Hawk*

General

Global Hawk, formerly identified as the Conventional High Altitude Endurance (CONV HAE) or Tier II+ UAV, is planned as the HAE UAV "workhorse" for missions requiring long-range deployment and wide-area surveillance or long sensor dwell over the target area. It will operate at ranges up to 3,000 nm from its launch area, with on-station loiter capability of 20 hours (at that range) at altitudes exceeding 60,000 ft. It will employ both EO/IR and SAR sensors to generate both wide-area and spot imagery while standing off from high-threat areas. It will have both LOS and satellite data link communications. The HAE Common Ground Segment (CGS) (see p. 35) provides both launch and recovery and its mission control elements (LRE and MCE), which are common and interoperable with *DarkStar.* The ACTD is in Phase II, which comprises fabrication and an extensive system test program to assure AV subsystem functions and AV-ground segment integration, to demonstrate system capabilities, and to reduce risk. Prime contractor is Teledyne Ryan Aeronautical (TRA), San Diego, CA.

Subsystems
Air Vehicles (TBD)
1 Common Ground Segment

Flight #1: Scheduled for January 1998

Key Operational Factors			
Sensors:	EO, IR and SAR	Radius:	5,556 km (3,000 nm)
Deployment:	AV: self-deployable; multiple C-141/C-17/C-5 sorties for other equipment[a]	Endurance:	38 hrs (20 hrs at radius)
		Max Altitude:	19.8 km (65,000 ft)
		Cruise Speed:	639 km/hr (345 kts)

[a]Depends on equipment deployed and deployment duration

Funding (Then-Year $M):	**FY97**	**FY98**
• RDT&E (Defense-wide)	67.8	96.0

FY 1997 Activities and Flight Preparations

ACTD Component	Adjustment
• *Global Hawk*	8 to 5
• *DarkStar*	6 to 4*
• HAE CGS	3 to 2

* Including AV-1 (crashed April 1996)

Following ACTD Phase II contract award in May 1995, the TRA team fabricated the first two AVs and performed subsystem and system integration tests throughout the year. AV-1 will be used for airworthiness evaluations and full flight envelope demonstration, while AV-2 will carry the full sensor suite for system evaluations.

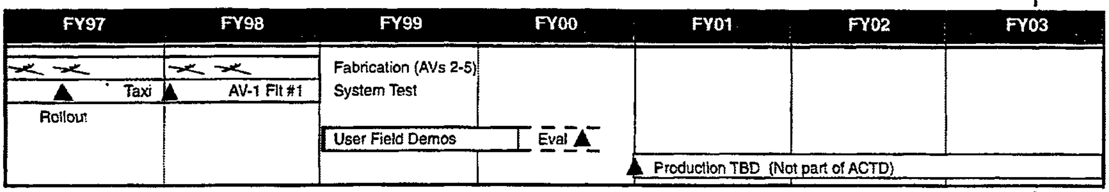
In a USD(A&T)-directed approach to remain within available ACTD funding, air vehicle production has been reduced and Phase III shortened from 24 to 15 months.

1997	Subsystem Milestones
Jan	Successful test of environmental control systems
Jan	Delivery of first Integrated Mission Management Computers (IMMCs)
Mar	First "live" engine run (following initial dry and wet checks)
Apr	Flight test mission profile simulated (using LRE, System Integration Lab), and communications system simulators (connected by Ethernet)
Apr	Final software integration and testing in preparation for Flight #1
Jul	Ground testing for electromagnetic interference (EMI) characterization
Aug	AV-1 relocated to Edwards AFB, CA, for taxi and flight tests
Oct	SAR flight tests initiated on A-3 test aircraft
Oct	All AV-1 subsystems rechecked for flight readiness. Initial taxi tests

Rollout of AV-1 took place at TRA's San Diego, CA, facility on 20 February 1997. By then, almost all subsystems required for first flight had been installed, but the full system's software development and integration required more time. On 28 August, TRA transported AV-1 to the Air Force Flight Test Center at Edwards AFB, CA. During the next few weeks, the system was reassembled and functionally retested. Taxi testing began in October, with AV-1's first flight planned for January 1998.

A Strategic Asset with Which to See "The Big Picture"

Schedule



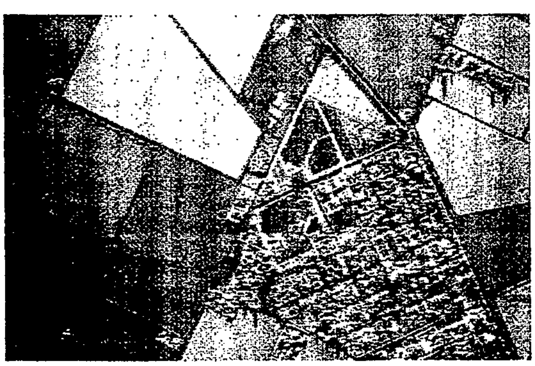
Near-Term Plans

Phase II will extend to 1Q/FY 1999, followed by Phase III, Test and Field Demonstrations, which will enable early user involvement in both technical and operational demonstrations to evaluate military utility.

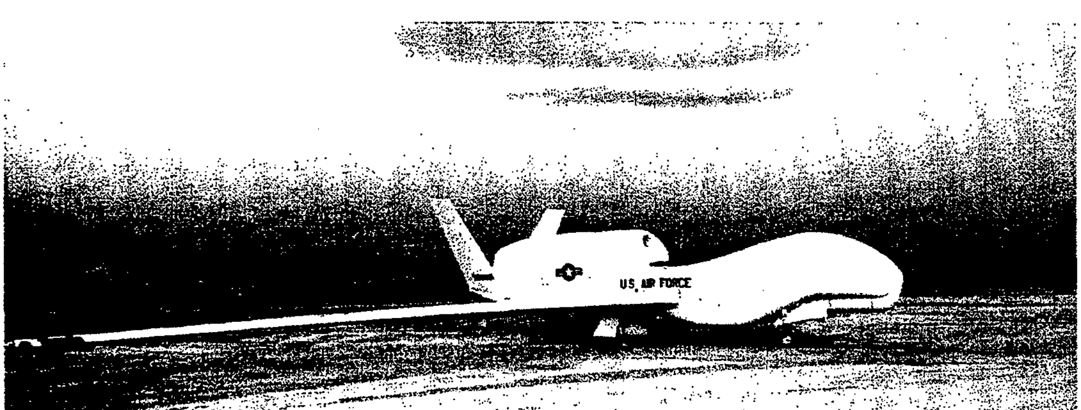
Program management is scheduled to transition from DARPA to an Air Force joint program office during the second half of FY1998. In addition, the following processes have been put in place:

- Early user participation is reflected by extensive Air Force involvement in the DARPA ACTD; and
- Early establishment of a sustainment team will ease *Global Hawk's* transition to an acquisition program and eventual operations (in the event of a favorable ACTD exit decision).

Phase II will consist of a series of airworthiness flights by AV-1 and -2, followed by EO/IR and SAR payload flights by AV-2. Following demonstration of basic system abilities to fly safely and relay imagery to the ground, AV-1 and -2 will enter Phase III, flying in their first joint exercise in January 1999. AV-3, -4 and -5 will join them in flying more than 50 sorties and 1,000 hours over the ensuing 12 months for users to assess *Global Hawk's* military utility by the time the HAE ACTD ends on 31 December 1999.


SAR image of Tranquillity, CA, at 65 km (35 nm)


EO imaging of Palos Verdes Estates, CA, at 21 km



Global Hawk's initial taxi test at Edwards AFB, CA, 16 October 1997

At *Global Hawk's* rollout ceremony, 20 February 1997:

"Global Hawk, *with its 14,000 nautical mile range ... will become a strategic asset ... to see the 'big picture,' to see it broadly, and to see it clearly."*

Dr. Kaminski, USD(A&T)

"'One peek is worth a thousand sweeps'... if you can get your eyeball on the target, it's worth a thousand sweeps of your radar, and what this vehicle promises to give us is that peek, that visibility, into what is going on across our battlefield, so that our forces can have that precious commodity that we call 'situational awareness.'"

Gen Richard E. Hawley Commander, ACC

Information Dominance is a necessary element for ... winning quickly, decisively, with few casualties. And ... I think Global Hawk *can be a key element of doing that.*

Lt Gen George K. Muellner Princ. Dep. SAF/AQ

RQ-3A *DarkStar*

General

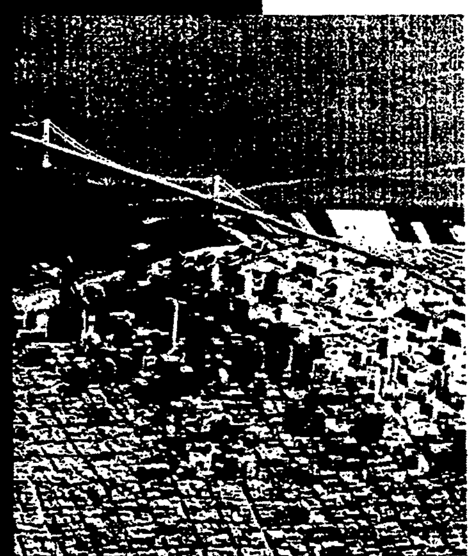
DarkStar, formerly identified as the Low Observable High Altitude Endurance (LO HAE) or Tier III– UAV, is designed to provide critical imagery intelligence from highly defended areas. With its use of low observable technology to minimize the air vehicle's detectability, *DarkStar* trades air vehicle performance and payload capacity for survivability features against air defenses. Its payload is either SAR or EO. The air vehicle may be self-deployable over intermediate ranges. The HAE Common Ground Segment (CGS) provides launch and recovery and mission control elements (LRE and MCE), which are common and interoperable with *Global Hawk. DarkStar's* prime contractor is the Lockheed Martin/Boeing team.

Subsystems	
Air Vehicles [TBD]	
1 Common Ground Segment	

Key Operational Factors	
Sensors:	EO or SAR
Deployment:	Multiple C-141/C-17/C-5 sorties
Radius:	>926 km (>500 nm)
Endurance:	12 hrs (8 hrs at radius)
Ceiling:	15.2 km (50,000 ft)
Cruise Speed:	556 km/hr (300 kts)

Funding (Then-Year $M):	FY97	FY98
• RDT&E, Defense-wide	55.1	54.6

FY 1997 Activities and Flight Preparations



EO imagery of the San Francisco Bay area, CA

DarkStar's Flight #2 crash (22 April 1996, following its successful first flight in March) led to several design and control changes to correct the porpoising motion that induced the crash and to make the flight control system more robust. The system changes were extensively modeled and incorporated into AV-2, which was converted to flight status after completing radar cross-section testing.

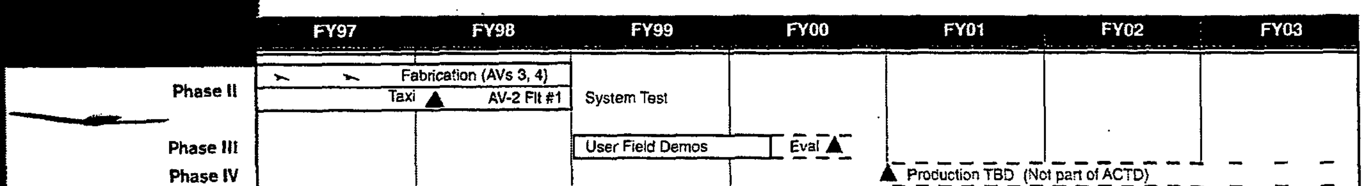
Other accomplishments included:

- ❒ A highly successful EO camera test (aboard a C-130 aircraft; see imaging of San Francisco at left);
- ❒ Critical air vehicle control and reliability modifications; and
- ❒ Upgrades to computers and the flight simulator.

Meanwhile, AV-3 and -4 are being fabricated for Phase III, Test and Field Demonstrations, which is now scheduled to begin in FY 1999.

DarkStar AV-2 was transferred to the NASA Dryden Flight Research Center, at Edwards AFB, CA, in October 1997, completes taxi tests in December, and is poised for a resumption of the flight test program early in 1998.

Schedule



HAE Common Ground Segment

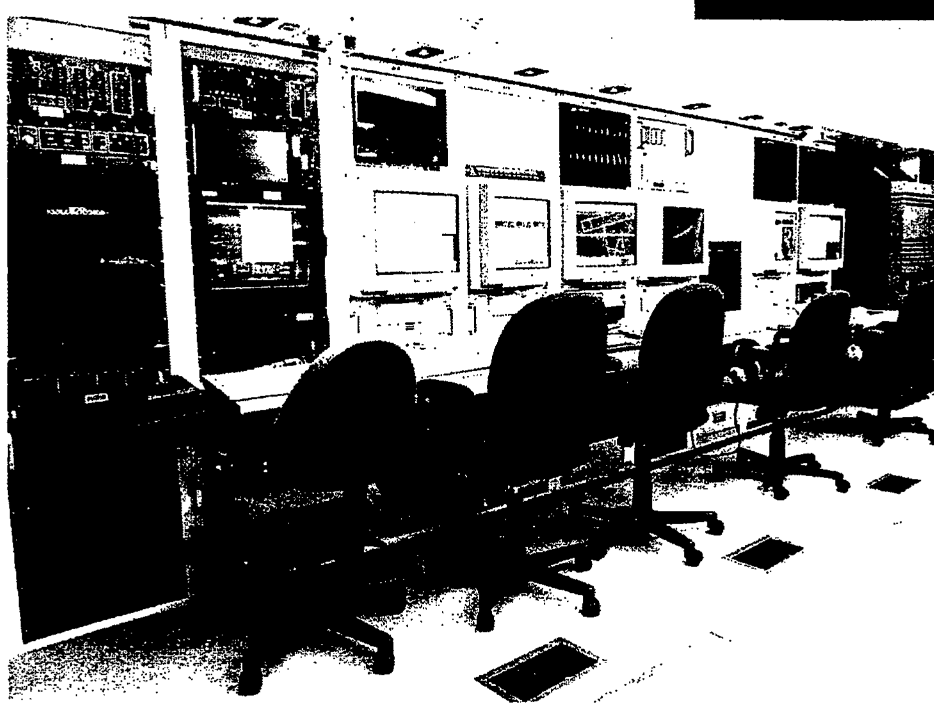
Funding (Then-Year $M):	FY97	FY98
• RDT&E, Defense-wide	57.8	42.1

Note: Other common, but non-CGS-related, costs are budgeted in this line. These include government test and evaluation efforts and program office support, studies, and related tasks.

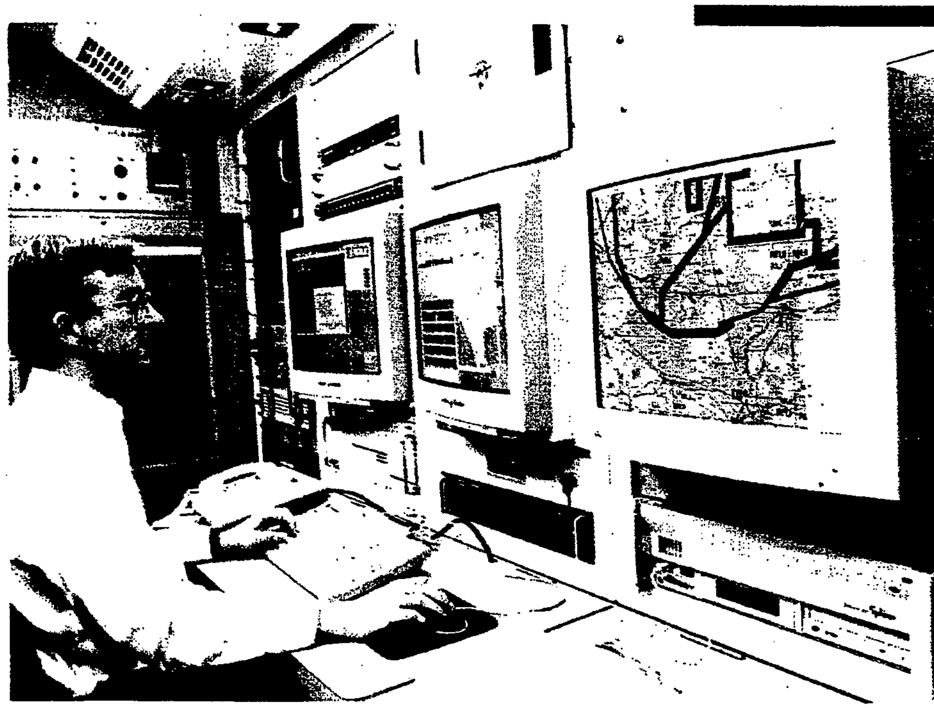
The third part of the HAE UAV system is its Common Ground Segment (CGS), which controls both HAE AVs. The CGS includes a Launch and Recovery Element (LRE), a Mission Control Element (MCE), a *DarkStar* Data Processing Element (DS DPE), associated communications, maintenance and support elements. The LRE prepares, launches and recovers the AV. The MCE plans and executes the mission, dynamically re-tasks the AV (including its sensors), and processes and stores or disseminates imaging and ground MTI data.

The HAE CGS will be able to control up to three HAE UAVs at a time by LOS data link and SATCOM relay, thus enabling a single system to maintain a continuous presence over many days and at extended ranges from the operating site. The AVs will transmit digital imagery to the MCE (and TCS) via wideband LOS or satellite links for initial processing and relay to theater and/or CONUS imagery exploitation systems (IESs) using standard (CIGSS-compliant) formats. Selected reports and imagery frames will be able to be broadcast directly. When linked with systems such as the Joint Deployable Intelligence Support System (JDISS) and the Global Command and Control System (GCCS), such unexploited digital imagery will be transferable in near-real-time to the operational commander for immediate use. Thus, the HAE CGS will provide digital, high-quality imagery to warfighters and users at various command levels.

During the ACTD's Phase III, the full HAE UAV system will take part in exercises, demonstrations, and possible contingency deployments. The MCE and LRE pictures (above-right) show the Ground Segment's progress from last year's designs to this year's hardware.



HAE CGS Mission Control Element (MCE)



HAE CGS Launch and Recovery Element (LRE)

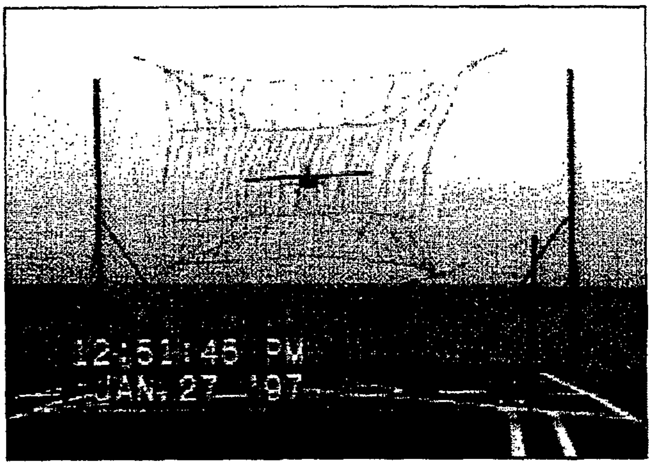
Key Subsystem Programs

UAV Common Automated Recovery System (UCARS)

UCARS has been developed to improve the precision, ease and safety of UAV recoveries, both on land and afloat, and in most kinds of weather and operating conditions. UCARS comprises a common position sensing system (provided by Sierra Nevada Corp., Reno, NV) and UAV-specific guidance and control software (developed by each UAV's prime contractor). The position sensing system is a millimeter-wave transponder tracking radar.

From September through December 1996, UCARS was successfully ground- and flight-tested aboard VC-6's *Pioneer* system at Webster Field, MD. Shipboard flight testing aboard the USS Shreveport, 20 – 31 January 1997, resulted in seven successful net recoveries and fully demonstrated UCARS' operational utility. Suitability testing of the first production UCARS unit began in May 1997. It will be fielded on *Pioneer* in FY 1998 – 99.

UCARS integration into *Outrider* began in FY 1997, while *Predator* integration will be started in FY 1998. A VTOL-UCARS demonstration is an option of the VTOL BAA (see p. 11). TCS will also incorporate the ability to recover AVs using UCARS.



UCARS-aided *Pioneer* recovery aboard the USS Shreveport

UCARS Track Subsystem

Modular Integrated Avionics Group (MIAG)

MIAG (left) will replace the components at right, plus wiring (not shown).

MIAG is a new, lightweight avionics package designed to replace multiple UAV avionics subsystems, improve UAV flight performance, and reduce weight and cost. Its initial application is on *Pioneer*. The 15-lb MIAG unit's functions include primary and backup navigation, flight stability control and processing, engine interface and control, mission loading and verification, payload control, Mode 4-capable Mark XII IFF, in-flight mission updating, data link management, built-in test and monitoring, and internal power sources. This multi-subsystem upgrade will increase many-fold the reliability of the relevant *Pioneer* functions, improve the AV's center of gravity, and reduce weight by up to 40 lb. This in turn will make room for larger payloads.

A MIAG engineering development model was integrated with Pioneer and flown successfully in July 1997. Production and full *Pioneer* fleet retrofit are planned, with the first incremental contract award in mid-FY 1998. Prime contractor is Lear Astronics, Santa Monica, CA.

Tactical Common Data Link (TCDL)

The objective of the TCDL program is to develop a lightweight, low-cost, CDL-interoperable data link for smaller UAVs and selected manned reconnaissance aircraft. The TCDL will support air-to-surface transmission of radar, imagery, video and other sensor information at ranges up to 200 km. It will interoperate with existing CDL systems operating at the 10.71-Mbps return link and 200-kbps command link rates. Programmable TCDL design features will enable the system to operate at up to 45 Mbps using commercial products and waveforms, while still retaining CDL interoperability.

TCDL program goals are to:

- ❐ Increase capability of, and lower costs and increase competition for, CDL-interoperable equipment; and
- ❐ Emphasize an open systems architecture using state-of-the-art communications technology and COTS systems and components.

Its six-month Phase I design study for the began in May 1997 with awards to three contractor teams:

- ❐ L3 Com and Rockwell Collins;
- ❐ Harris, GEC Marconi-Hazeltine, and TSI; and
- ❐ Motorola, Raytheon E-Systems, and Cubic.

Phase II's design, build and test work will start in January 1998. The goal of Phase II is to develop multiple TCDL-certified vendors.

Heavy Fuel Engine (HFE)

DoD HFE Development Program

Following the June 1997 USD(A&T) decision to remove the HFE option from the TUAV ACTD, a separate HFE development project has been established under DUSD(AT). A committee representing several OSD and Service offices met to focus DoD and industry efforts on HFE maturation and application to relatively small platforms, from UAVs to a variety of surface vehicles and equipment. At this stage, a common HFE family appears infeasible, due to the lighter weight-to-power density of 1.5 lb/hp for UAVs vs. 2.5 lb/hp with more stringent emission requirements for ground vehicles, and also projected differences in load requirements, cooling, and production quantities. However, significant common technology applications at the subsystem and component level show promise (e.g., for compressors, fuel pumps, injectors, rings, and perhaps even pistons, rods, and valves). The committee believes that it may be feasible to develop a prototype HFE for UAVs based on current lightweight automotive engine work that meets TUAV requirements.

Commercial HFE Initiatives for UAVs

Some companies are already pursuing their own HFE initiatives for their UAVs:

- ❐ **HFE Demo for *Pioneer*.** In October 1997, PEO(CU) contracted with Sonex Research Inc., Annapolis, MD, to convert two *Pioneer* gasoline-fueled engines to heavy fuel and demonstrate their operation in April 1998. This award follows Sonex's flight demonstration of a smaller engine conversion for the Naval Research Laboratory.
- ❐ **HFE for *Predator*.** General Atomics has an in-house effort to develop an HFE for *Predator*.
- ❐ ***Hunter* HFE Development.** The Williams HFE that was being developed for *Hunter* may also have potential for other UAVs (including *Predator*). The Williams HFE had progressed to Critical Design Review (CDR) before the effort was halted as part of the *Hunter* UAV program termination.

UAV Mission / Payload Prioritization

In last year's Report, we noted the initiation by the JROC's UAV Special Studies Group (SSG) of its follow-on UAV payload prioritization work, according to UAV and projected mission or capability areas. This past year, the UAV SSG iterated both mission priorities and payloads by UAV with the Service and operational CINC staffs to develop a consolidated set of recommendations to suggest future technology investment. Current status is reflected below.

Mission	TUAV	Predator	Global Hawk	DarkStar
Reconnaissance – Improved Day / Night All-Weather Surveillance – Improved Target Geolocation – Battle Damage Assessment (BDA)	1	1	1	1
Signals Intelligence (SIGINT)	6	2	2	3
Mine Countermeasures	2	6	12	10
Target Designation	3	3	9	2
Battle Management	4	8	7	6
Chemical/Biological Reconnaissance	5	10	11	9
Counter-Camouflage/Concealment/Deception	7	4	6	4
Electronic Warfare	8	7	4	8
Combat SAR [Search and Rescue]	9	5	10	5
Communication / Data Relay	10	9	3	11
Information Warfare	11	11	5	7
Digital Mapping	---	12	8	12
UAV Mission-Payload Considerations	Improve current sensors to support economic, rapid fielding of upgrades		Emphasize "plug and play" sensors (see below) Create LOS comm/data relay within Theater	Emphasize sensors that take advantage of DarkStar's stealth attributes

Mission payload defined

CINC/Service UAV Mission Prioritization

First, the CINCs prioritized the missions (at left) for each of the four future-force UAVs, as shown. Reconnaissance in all its major aspects is clearly seen as the primary warfighting role for all UAVs, no matter what their capabilities or operating régime. The other missions may have higher or lower priorities for each UAV, depending on that UAV's characteristics. Payloads that have already been defined for specific UAVs and roles are shown in color. UAV-specific considerations are below the table.

Notional consolidated UAV-payload lists have been developed for each operating régime — Tactical and High Altitude — as options for post-ACTD program decisions. Cost and schedule factors were included to test for feasibility and affordability. These lists are shown at left. *Outrider* and *Predator* were envisioned in more tactical roles, while *Global Hawk* and *DarkStar* would perform in scenarios that required high operating altitudes. The mission functions that each UAV-payload option could perform are shown in the right column.

Some payloads will need corresponding improvements in communication links and data-processing capabilities, whether on- or off-board the UAV, to capitalize on the payload's capability; for simplicity, these are not shown. In addition, some manned platform payloads are being considered for UAVs also, such as improved SIGINT, Advanced Synthetic Aperture Radar System (ASARS) and Senior Year Electro-optical Reconnaissance System Multi-Spectral Imagery (SYERS MSI).

Notional Future Payloads

	UAV	Payload	
TACTICAL	Predator	Improved Video (EO/IR)	Recce, BDA, Day/Night (D/N) Adverse Wx
	Outrider	Improved IR (MWIR)	Recce, D/N Adverse Wx, BDA
	Outr / Pred	Digital Data Link	(Sensor-Dependent)
	Outrider	SAR / MTI [a]	Recce, D/N All-Wx, Impvd Tgt Geoloc, BDA
	Predator	Improved LWIR	D/N Adverse Wx, Recce, BDA
	Predator	MTI Radar [a]	D/N All-Wx, Recce, Impvd Tgt Geo, BDA
	Outrider	Mine CM: Land,[a] Beach	Recce, Mine Countermeasures
	Outr / Pred	Comm / Data Relay	Comm / Data Relay
HIGH ALTITUDE	Global Hawk	JSAF Payload (SIGINT) [b]	Recce, SIGINT
	Global Hawk	Airborne Comm Node	Comm / Data Relay
	Global Hawk	ASARS Impv Pgm (AIP) [b]	D/N All-Wx, Recce, BDA
	Global Hawk	EO / IR (SYERS MSI) [b]	Recce, BDA, Counter-Camou / Con / Decep
	Global Hawk	Interferometric SAR	Recce, Tgt Geolocation, Digital Mapping
	DarkStar	Add IR	D/N Adverse Wx, Recce, BDA
	DarkStar	Laser Designator	Tgt Geolocation, Tgt Designation
	Global Hawk	FOPEN Radar	D/N All-Wx, Recce, Counter-CCD
	Global Hawk	Stand-off Jammer	Electronic Warfare
	DarkStar	Improved SAR Resolution	D/N, All-Wx, Recce, BDA
	Global Hawk	ESM Imagery Cueing	D/N, All-Wx, Recce, ELINT, Impvd Tgt Geo
	Global Hawk	Impvd Squint SAR (GH)	D/N, All-Wx, Recce, BDA
	Global Hawk	Impvd GMTI Mode (GH)	D/N, All-Wx, Recce
	Global Hawk	Imp Resol SAR (2x) (GH)	D/N, All-Wx, Recce, BDA
	DarkStar	Add GMTI Radar	D/N, All-Wx, Recce

[a] Requires Digital Data Link [b] Integration for "Plug and Play" with U-2 and Air Force Special Platform

Payload Test and Demonstration Programs

At the hardware application and integration level, payload testing and demonstration programs for tactical applications are conducted or supported by the PEO(CU).[13] These continuing activities combine emerging technologies with operational concepts to provide an expanding menu of capabilities for fielding aboard the DoD's evolving family of UAVs.

The FY 1996 payload demonstrations that were reported in FY 1997 are combined with FY 1997's demonstrations in the table below. During this time frame, the PEO(CU) also participated in several operational exercises, to provide more convincing demonstrations of UAV and payload capabilities and utility. These activities are tabulated on p. 9.

[13] Specific payload and subsystem applications within the HAE UAV ACTD are conducted by DARPA and are covered in the *Global Hawk* and *DarkStar* program descriptions.

Demonstration Payload	Potential Mission Application	Host UAV	Report
Coastal Battlefield Reconnaissance and Analysis (COBRA)[a]	- Detect mines (day / limited visibility)	*Pioneer*	Nov 96
Signals Intelligence (SIGINT) Payload[a]	- Locate/ID enemy ground emitters	*Hunter*	Nov 96
Radar Jammer Payload[a]	- Jam enemy ground radars	*Hunter*	Nov 96
Communications Jammer Payload[a]	- Jam both radios and data links	*Hunter*	Nov 96
ALE-47 Dispenser Integration:			
– Remote control standard payload dispenser system[a]	- Non-lethal crowd control	*Exdrone*	Jun 97
		Hunter	(Jan 98)
		Pioneer	(Mar 98)
– Tactical Meteorological Dropsonde System (T-Drop)[a]	- Demo of near-real-time weather data from remote/denied areas	*Predator*[b]	Sep 97
		Pioneer	(Mar 98)
– Chemical Agent Dual Detection Identification Experiment (CADDIE)[a]	- Chemical agent detection	(TBD)	(TBD)
Anti-Personnel Land Mine Replacement[a]	- Force protection	(TBD)	(< 2 yrs)
Orion Wideband Intercept Relay[a]	- Find, relay ground comms emitters	*Hunter*	Jul 97
Versatron DS12 with Laser Range Finder	- Target location	*Pioneer*	Jul 98
Versatron DS12 with Laser Designator[a, c]	- Target designation	*Pioneer*	(TBD)
Tactical Remote Sensor System (TRSS)	- BLOS ground sensor relay	*Pioneer*	(TBD)
Airborne Standoff Mines Detection System (ASTAMIDS)	- Mine countermeasures	*Hunter*	(TBD)
Synthetic Aperture Radar (SAR)	- All-weather reconnaissance	*Pred / Out*	(TBD)
Precision Location (sensor and algorithms)	- Precision target location	*Pioneer*	(TBD)

[a] Sponsored by other agencies [b] Mounted in a conformal pod [c] Possible common support for T-Drop sensor relay

The Army's Night Vision Electronic Sensors Directorate (NVESD) is testing a variety of EO/IR and Measurements and Signals Intelligence (MASINT) sensors aboard four *Sentry* UAVs recently acquired from S-TEC Corp. Although the immediate customer is the Army's Intelligence and Security Command (INSCOM), these efforts will ultimately benefit tactical UAV users.

TCS Demonstration Aboard USS Tarawa

TCS was integrated aboard the USS Tarawa for a demonstration during the November 1997 Fleet Exercise (FLTEX), using the *Gnat 750* (with MUSE as a backup simulation tool). In addition, data was received from a *Pioneer* flown off the USS Denver. TCS Levels 2 and 4 (direct data receipt, and UAV and payload control, respectively) were successfully demonstrated. TCS disseminated video imagery and telemetry data via closed-circuit television (CCTV) and the Joint Defense Intelligence Support System (JDISS). Additionally, UAV data was transmitted via tactical communications to users for incorporation into the exercise.

Multiple UAV Simulation Environment (MUSE)

MUSE was developed by the Joint Technology/Systems Integration Laboratory (JTSIL) to provide real-time operator-in-the-loop simulation of multiple UAVs. MUSE provides a realistic UAV environment for UAV systems integration, exercises, experiments, demonstrations, CONOPS development, and training. It is hosted on Silicon Graphics Onyx and Sun SPARC computer hardware and is fully transportable to user locations. The system currently simulates operations of *Pioneer, Hunter, Outrider, Predator,* and prototype TCS; it will incorporate HAE UAVs in FY 1998. MUSE systems are currently provided at six Service locations.

Technology

Technology Programs

In January 1996, the USD(A&T) first discussed ten primary "enabling technologies and architectural concepts that are needed to build dominant battlefield cycle times." All are relevant to airborne reconnaissance, and most are currently being applied to or planned for various programs. Their UAV applications are shown in the table below.

Application of Key Enabling Technologies to UAVs

Key Enabling Technologies:	Outrider	Predator	TCS	Global Hawk	DarkStar	CGS
1. Advanced Processing (On-/Off-Board Processors)	X	X	X	X	X	X
2. Automatic Target Processing (Imagery Analysis Productivity Tools)	X	X		X	X	
3. Common Grid Reference (Enhanced Data Fusion)			X	X		X
4. Distributed and Open Architectures (e.g., JASA)			X	X		X
5. Sequential Application of Off-Board Collectors				X		
6. Data Compression	X	X	X	X	X	X
7. Very Large, Dynamic, Object-Oriented Data Bases						
8. Data Storage			X			X
9. Data Dissemination (interface to user/warfighter)		X	X	X	X	X
10. Planning Analysis Tools (e.g., Mission Planning tools)			X			X

DARO's Airborne Reconnaissance Technology Focus

DARO's "systems" approach to technology applications leverages both commercial and other government technologies to maximize its investment. Its three major focus areas are Advanced Technology, Advanced Sensors, and Communications (Common Data Link).

Advanced Technology

This program funds research, advanced development and demonstrations of maturing technologies to facilitate their applications and a transition to DARO's future objective airborne reconnaissance architecture. The current technology transition activities most applicable to UAVs are shown below.

Technology Transition Program Activity

FY 1997	FY 1998	Remarks
Reconfigurable Pods		Near-term focus on manned recce; UAV applications later
Precision Geolocation		**SIGINT:** Cooperative geolocation demonstrations **IMINT:** Development of passive radar tags and imagery registration techniques
SIGINT Upgrades	**SIGINT Technology**	Modular, incremental JSAF approach. Multi-use antenna study for SAR / Comms / SIGINT
Automatic Target Recognition (ATR) & Correlation		Demos of moving target exploitation performance and functionality in JSTARS virtual testbed. Demo Intelligent Bandwidth Compression (IBC) real-time application to U-2 and *Global Hawk*. Transition of semi-automated IMINT processing (SAIP) ACTD to operations
Exigent Target Detection		Conduct evaluation tests of hyperspectral imaging (HSI) sensors on a UAV
CDL and Advanced Technology		Enabler of UAV (and manned system) interoperability
High-Data-Rate (HDR) Uplinks and Crosslinks		Complete and demo laser terminal air-to-air
Heavy Fuel Engines	**Common Systems Development** [a]	Support development of advanced HFE for UAVs
Integrated Avionics	**Common Systems Development** [a]	Integrated, tested and now acquiring Modular Integrated Avionics Group (MIAG) for *Pioneer*
MSAG	**Common Systems Development** [a]	Completed the prototype Active Array antenna (MSAG = Multifunction Self-Aligned Gate)
Framing Reconnaissance Cameras	**Common Systems Development** [a]	Developing IR versions of 4-mega-pixel (MP) and 25-MP EO framing cameras. Continuing multispectral and compression algorithm technology developments

[a] DARO's HFE request not funded in FY 1998 Appropriations Act (DARPA may fund for FY 1998); MIAG funded in *Pioneer*; MSAG and cameras funded under DARO's Advanced Technology program.

Common Data Link (CDL)

Description: The CDL and Tactical CDL (TCDL) provide configuration-controlled and standardized wideband, digital, secure communication paths between multiple reconnaissance sensors and their users (e.g., *Predator, Global Hawk,* and *DarkStar).* TCDL also supports development of the lighter-weight lower-cost units for the TUAV *(Outrider)* and *Predator.*

FY97 Highlights	FY98 Plans
• Continued Airborne Information Transmission (ABIT) preliminary design for platforms • Began Tactical CDL development • Leased comsats supported *Predator* and HAE UAV activities	• Continue TCDL development • Support UAV testing, training, ing, and deploy-ments

Advanced Sensors

Description: This program funds improved sensors from successful Advanced Technology proof-of-concept efforts and conducts sensor prototype demonstrations, which are turned over to Services for procurement and platform integration. It also identifies multispectral imaging (MSI) technologies for sensor system upgrades.

FY 1997 Highlights	FY 1998 Plans
• Improved *Predator* image quality and utility • Increased night contrast • Eliminated motion artifacts	• Improve *Predator* system location accuracy, and general system optimization

The following table summarizes other UAV-related technology projects that DARO funds or otherwise supports, in cooperation with Service or other government agency initiatives.

Current UAV Technology Applications

Heavy Fuel Engine (HFE)

- Objective: Provide UAVs with a safe, readily available fuel for DoD system commonality
- Status: Following U.S. and international developments to satisfy an urgent need for reliable, lightweight (1 lb/hp) HFEs for UAVs

Joint SIGINT Avionics Family (JSAF)

- Objective: Open-architecture suite of sensors based on Joint Airborne SIGINT Architecture (JASA) (currently for manned aircraft, but potentially applicable to UAVs)
- Status: Development continues, but UAV engineering and compatibility studies postponed

Laser Designator/Rangefinder (LDRF) Payload

- Objective: Accurate targeting for precision guided munitions (PGMs) without risk to aircraft or ground spotters
- Status: An off-the-shelf payload was integrated into a *Hunter* and successfully demonstrated in FY96. An LDRF demonstration is being planned for *Outrider*

Mine Countermeasures Payload

- Objective: UAV-borne mine detection capability to avoid risk to ground troops and naval forces.
- Status: Integration of the Coastal Battlefield Reconnaissance and Analysis (COBRA) payload on TUAV by early 2003

Downsized Synthetic Aperture Radar (SAR) (Tactical SAR)

- Objective: Affordable, lightweight SAR sensors to increase UAV flexibility and performance.
- Status: Planning integration in TUAV in 2002. Payload includes 0.3 and 1.0 m resolution spot mode

Communications/Data Relay Payload (CRP)

- Objective: Routinely use UAVs for airborne relay to free manned aircraft for other missions
- Status: A CRP was successfully demonstrated aboard a *Hunter* in FY96

Air Vehicle Electromagnetic Interference (EMI)

- Objective: Design and produce air vehicles whose EMI environment allows successful SIGINT, communications relay operations
- Status: Initial *Predator* EMI reduction effort completed successfully

Global Positioning System (GPS) Pseudolites

- Objective: Enhance warfighter resistance to GPS jamming by rebroadcasting GPS data from UAVs
- Status: Continue tracking Navy and DARPA GPS pseudolite programs

Interferometric SAR (IFSAR)

- Objective: Improve geolocation accuracy by developing a single-pass HAE IFSAR capability
- Status: Joint effort with the ACTD sensor development by 2002

Wideband SAR (Foliage Penetrating **[FOPEN] Radar)**

- Objective: Improve all-weather detection of targets concealed by foliage or camouflage
- Status: Continue to develop a sensor for integration on TUAV by 2001

Focal Plane Arrays (FPAs)

- Objective: Develop large-format FPAs for improved imaging compared to film or line scanning sensors
- Status: 25-Megapixel FPAs demonstrated

Hyperspectral Imaging (HSI)

- Objective: Improved detection of hidden or camouflaged objects by spectral discrimination
- Status: Hyperspectral sensors for *Predator* to permit real-time tactical cueing of on-board cameras

Video Imagery (per DSB Task Force on Improved Applications of Intelligence to the Battlefield, Jul 96)

- Objective: Improve video image quality, and provide cataloguing, retrieval and exploitation capabilities
- Status: Improve *Predator* video to provide advanced reconnaissance, day/night and adverse weather capabilities, BDA, and battle management functions

Automatic Target Recognition (ATR)

- Objective: Improve target discrimination in wide-area imagery, and minimize data link bandwidth
- Status: Joint DARO/DARPA program to develop multisensor exploitation testbed employing spectral, moving target exploitation (MTE), FOPEN ATR techniques

Common Systems Development

- Objective: Pursue development and production of systems common to the tactical family of UAVs
- Status: Support of testing, system integration and subsystem development, including UCARS and MIAG. Demonstration of alternative UAV technologies and concepts (e.g., VTOL and HFE)

DARPA Technology Initiatives

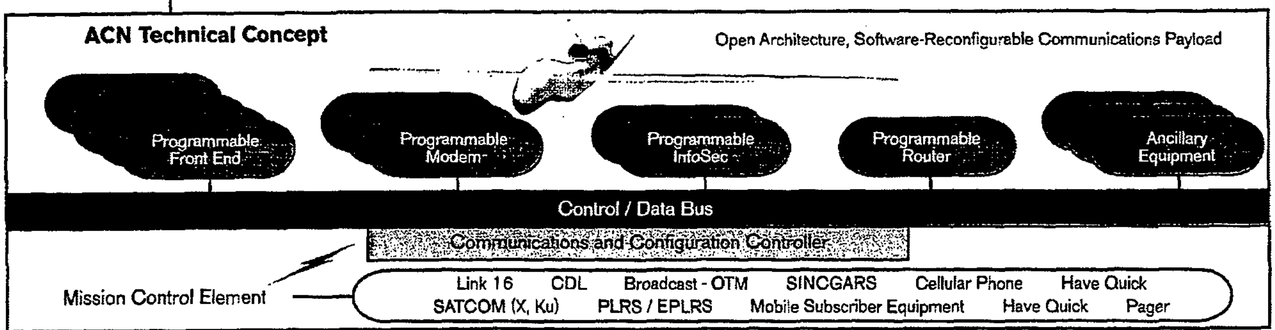
Airborne Communications Node (ACN)

DARPA's ACN program will develop a prototype communications payload for deployment on long-endurance platforms, using advanced technologies also under DARPA development.

ACN's theater-wide communications will help share information within and among joint forces. Its modular, software, reprogrammable radio and open system architecture will support multiple communication services, to include internet-like networking for joint warfighters. It will provide new mobile routing of cellular/personal communications services, and extended VHF and UHF radio capabilities, thereby enabling over-the-horizon connectivity for isolated or rapidly moving forces. It will feature robust gateways, bridging, routing, broadcast, paging, and multimedia services. The network may be extended to other aircraft through air-to-air crosslinks to form a self-organizing backbone. ACN's value will be seen in rapid force projection, where its network synchronism and multiple services will improve the battle management of early entry and general expeditionary forces.

FY97 Highlights	FY98 Plans
• Completed four technology studies • Contracted for Advanced Digital Receiver and RF-tunable MicroElectro-Mechanical System (MEMS)	• Contract for expanded frequency coverage for the RF MEMS filters, advanced digital transmitter and power amplifier, and an advanced infosec module and router[a]

[a] All these modules are designed around a peripheral control interface (PCI) bus and credit card-sized Personal Computer Memory Card International Association (PCMCIA) module.



Micro-Air Vehicles (MAV)

Micro Air Vehicle scale model

DARO is supporting a DARPA initiative to develop a micro-air vehicle (MAV), defined as a UAV measuring less than 15 cm (≈ 6 inches) in any dimension while carrying a miniaturized payload, simple avionics, and a communication link. This new class of UAV would be ideal for employment by small, mobile units operating in environments such as urban areas or unconventional operations anywhere. At the same time, the MAV presents a combination of technical challenges, as the sub-15-cm régime involves changes in the way things fly in terms of the physics of aerodynamics and flight control. Modern materials, microsensors and study of the flying techniques of small birds and insects will all contribute to MAV development.

FY 1997 activities included: a military applications workshop at Ft. Huachuca, AZ (October 1996); an emerging technologies seminar at Georgia Tech Research Institute, GA (February 1997); and a conference on targeting and gun-launched applications at Aberdeen Proving Grounds, MD (April 1997). Longer-term challenges include integration of the multiple new technologies, and assuring both affordability and simplicity of operation and support in the field. DARPA plans to spend $35 million during FY 1997 – 2000 on MAV feasibility determination. In late 1996, it awarded nine Small Business Innovative Research Phase I contracts of up to $100,000 each.

Issues and Challenges

Last year, our major challenges were in the areas of acquisition, technology, architecture, management approach, and operations. We have made significant progress in each of these areas, but new aspects emerge. As FY 1997 phases into FY 1998, they are as follows:

Acquisition Oversight

Our family of UAVs continues to be the best approach to meeting the JROC's multiple requirements. Sustaining *Pioneer* and using *Hunter* until new systems are available reflects a DoD-wide appreciation for UAVs' value. *Predator* is now firmly in production, the result of a solid post-ACTD transition process. The *Outrider* program has incurred a number of schedule delays, but increased oversight by the USD(A&T) and recent flight testing indicate that progress is being made. The HAE UAVs' flights are now taking place in FY 1998, after prudent delays to resolve technical issues. Both TCS and HAE CGS are being brought along to support their tactical and HAE UAVs and integrate their products with the C4I infrastructure.

The challenges that remain are those of all acquisition programs: how to "manage uncertainty" while bringing newly integrated systems to operational status and meeting program objectives in the standard areas of performance, cost, and schedule.

Technology

A combination of changing national roles and force structure in the face of stringent budgets enhances the role of technology as enabler of future capabilities. Many of the high-leverage technologies we have been maturing are now parts of subsystems and payloads that are being procured for fielded use (e.g., UCARS and MIAG). In turn, others are emerging for near-term focus and application in their turn (e.g., Tactical CDL). We will approach payload development in light of the JROC's emerging guidance, and in turn project new and varied military uses for our basic UAV platforms (e.g., Boost Phase Intercept, Communications UAV, and Uninhabited Combat Air Vehicle). Finally, integration of technologies is, in effect, another technology and offers as much challenge as any other aspect of system development.

Architecture

The DADT's interim report provides a first view of DARO's Objective Architecture and force structure projection for the 2010 time frame, as envisioned in DARO's *Integrated Airborne Reconnaissance Strategy* of 1994. Force mix and inventories sized for two MTWs should also suffice for routine and contingency operations. The report's roadmap projects eventual replacement of manned platforms by HAE UAVs for high-altitude missions and broad augmentation of manned platforms by *Predator* and tactical UAVs for medium- and low-altitude missions. The challenge architecturally will be to ensure (1) that Service UAV acquisition programs continue to meet joint requirements, and (2) that system interfaces and product interoperability factors continue to meet the needs of warfighters for comprehensive, accurate and timely information. The challenge analytically will be for DARO to develop and validate even more capable MS&A tools and techniques to support complex architectural and system-level trades as airborne reconnaissance migrates to the 2010 time frame.

Management Approach

Both DARO and the Department are accommodating to the recent changes in DoD organizational structure and oversight roles. What remains well proven, however, is the need for continuing, unified oversight of the many resource and functional aspects of airborne reconnaissance. The central roles played by DARO, the Joint Staff and many current DoD-wide processes have done much to rationalize airborne reconnaissance services and products for the warfighter, but the real payoff for UAVs will be in the projected fielding of those UAVs currently in ACTD status.

Operations

The continued presence of *Predator* over Bosnia and the series of FY 1997 exercises and demonstrations, in which UAVs proved their worth many times, are changing the way commanders view their battlefield. Ground commanders want responsive collection systems that provide critical information to enhance battlefield situational awareness, and UAVs must also show that they are sustainable logistically and can interoperate functionally with existing forces and C4ISR environments. Four operational subareas are noteworthy: multiple-UAV operations, airspace management, marinization, and imagery archival and retrieval. They are addressed in the following table.

Challenges	Activities
Multiple-UAV Operations *"We are just beginning to understand the operational impact of multiple-UAV operations...."* *(FY 1996 Report)*	*Hunter* first demonstrated multiple-UAV operation during a single mission in Apr 91, when one *Hunter* served as an airborne data link or relay, for control of another *Hunter,* during test. In April 1996, *Hunter* performed successfully as an airborne UHF/SINCGARS data relay: one *Hunter*, controlled from a forward control station, collected imagery while a second *Hunter* acted as its airborne data relay. General Atomics is now developing a similar capability with its *Gnat 750XP,* but from a single ground station. The company will enhance *Predator* operations in 1998 by adding the ability to control two *Predators* in flight simultaneously, one on-station and one en route to/from the operations area, from the same ground station. Thus, from initial multi-*Hunter* control (sometimes by multiple GCSs), multi-*Predator* control processes are under development, to include their operation through civil air space. In addition, concepts for operating UAV wingmen via a manned "mothership" and autonous UAV flights are being explored by Boeing and other contractors
Airspace Management *"We are continuing both national and international [airspace] coordination"* *(FY 1996 Report)*	The DoD Policy Board for Federal Aviation and the Air Force Flight Standards Agency (AFFSA) are leading DoD discussions with the Federal Aviation Administration (FAA) to allow unaccompanied UAV flights in the National Airspace System (NAS). Key issues to emerge from two 1997 meetings involve redefining the "see and avoid" concept, UAV-to-pilot ratios, inflight emergency procedures, and filing of clearances. New regulations (revised Order 7610.4) are now in negotiation for implementation in 1998
UAV Marinization *"...marinization seeks to provide UAV support for deep-water, littoral and amphibious operations..."* *(FY 1996 Report)*	In its *Predator* marinization feasibility study, the Navy examined adapting it for at-sea launch and recovery, as well as land-based maritime support. While modifications for sea-basing were deemed too complex and costly, the introduction of TCS aboard ships will provide capabilities to receive imagery and control the UAV's sensor and flight route without costly modifications to either ship or UAV. A TCS aboard the USS Tarawa (LHA-1) has already demonstrated receipt of imagery from both a *Gnat 750* and a *Pioneer* while operating off San Clemente Island, CA. For the next year, the Navy and Marine Corps will evaluate an *Outrider* system for maritime operations while concurrently exploring VTOL options and technologies
Imagery Archival/Retrieval *"We will need very large, dynamic, object-oriented databases...to store and transport imagery to...the warfighter..."* *(FY 1996 Report)*	During FY 1997, working with DARO the UAV JPO prototyped the inclusion of metadata in a *Predator's* data stream. The data were embedded in the closed-caption data fields. To ensure interoperability, DARO worked with the NIMA Video Working Group to develop a metadata standard for all video systems. The inclusion of metadata within the video stream enables automatic searching through the data archive to find the video clip of interest. A fully automatic archival system of the video data should now be feasible

Summary

The several challenge areas outlined above have all shown progress during the past year. At the same time, each issue resolved contains the seeds of a new challenge to be met. DARO's role has been to identify these cross-cutting, system- and architectural-level issues and provide guidance and oversight for their resolution, and we look forward to meeting the challenges of FY 1998 and beyond.

Director's Conclusion

Many challenges remain in UAV development if we are to continue to improve our performance of the intelligence, surveillance and reconnaissance mission and to develop new roles for the 21st century.

Enduring Challenges include:

- **Acquisition oversight** — the assurance of Department-wide coordination of all the players and processes that lead to the fielding of interoperable, sustainable and affordable UAV systems, as a growing part of our ISR capability. Cost is on an equal basis with performance.
- **Technology** — in all its facets, the great enablers of our evolving systems.
- **Architecture** — the emerging framework within which our UAV assets will play increasing roles, in conjunction with more traditional manned and overhead systems.
- **Operations** — the full-spectrum arena within which our UAVs will be fielded, our current focus is on multi-UAV activities, airspace management (especially coexistence with manned aircraft), marinization approaches to meet deep-water operational requirements, and the management of great quantities of imagery products and data.
- **Effective modeling and simulation tools** — to help quantify the military utility of UAVs and of airborne ISR generally. These techniques in turn become the bases for force mix trade studies to identify the optimal mix of assets to meet operational needs of the next century.
- **Control of program growth** — which involves both protecting our developmental UAV systems from "requirements creep" and not letting new concepts and missions drive our programs beyond performance capabilities. Our ongoing review of *Outrider* is sorting out how to proceed in meeting a broad range of multi-Service requirements, while our cautious approach to the impending HAE UAV flights indicates that our first focus must be on basics: first the birds have to fly and meet ACTD criteria; then their full capabilities can be explored and potentially expanded.

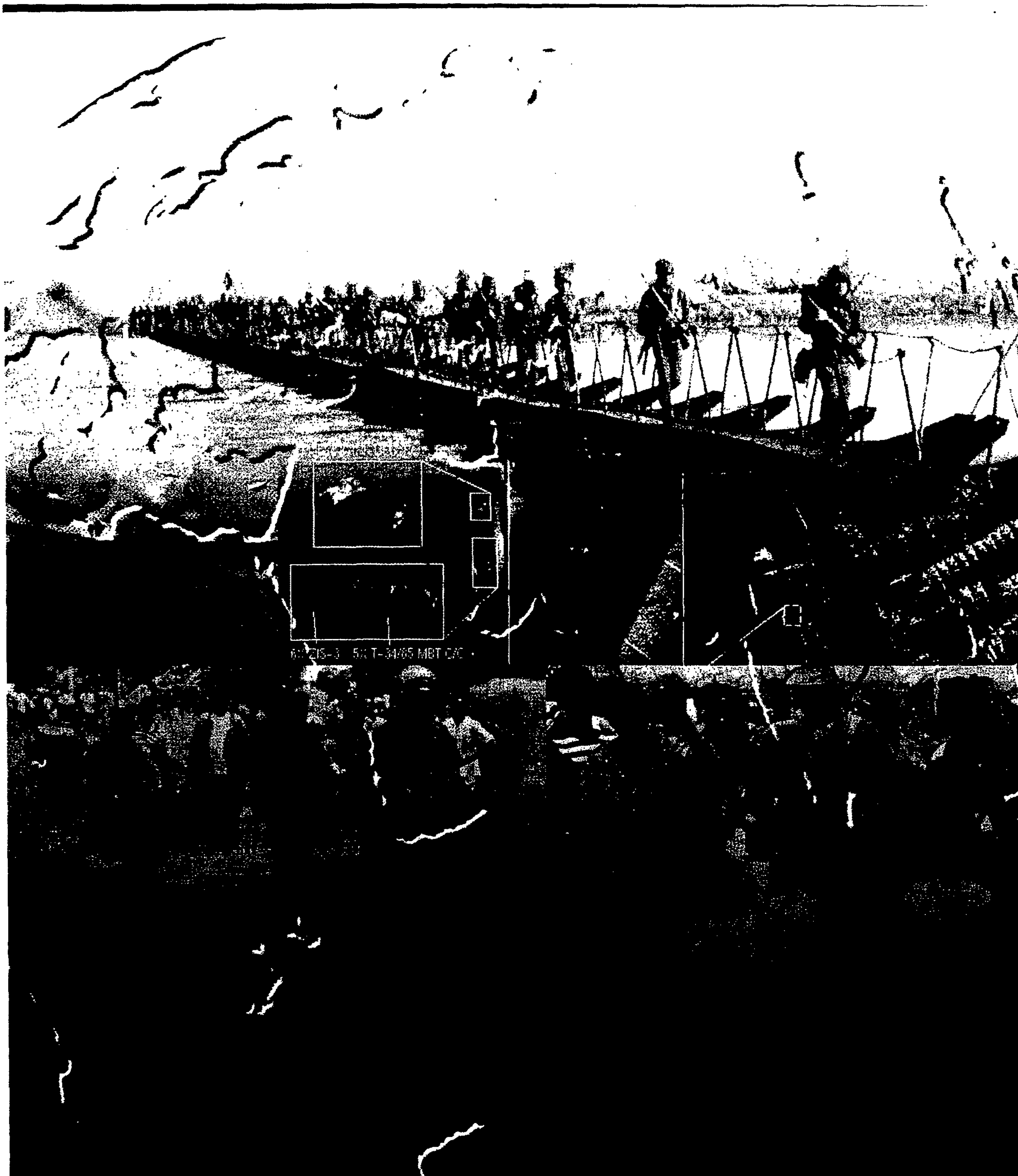
System Objectives include:

- **An HFE for tactical UAVs** — As part of the review process for the *Outrider* ACTD, HFE development was removed from the Tactical UAV program and initiated as a separate development effort. An HFE is critical to tactical UAV operations in that (1) it would use a more safe, reliable fuel already common to other aircraft systems, and (2) use of a common and safe fuel is crucial for UAVs operated and supported aboard ship.
- **Improved video product management** — We have begun to discover the value of video intelligence. Some estimates project that in the early 21st century over 90% of the pixels we collect will be from video sources. However, we have not yet resolved the problem of how to store, index and quickly retrieve the products. MPEG video compression will help reduce the video storage burden, but search and retrieval functions must also keep pace.
- **All-weather intelligence for the warfighter** — A continuing operational need is for accurate and timely intelligence regardless of weather. For this, we need to use synthetic aperture radar (SAR) techniques to see through clouds. As current SAR systems are relatively heavy, we need a SAR system sized for use on tactical UAVs.
- **Reduction of UAV vulnerabilities** — Now that UAVs are flying and meeting mission needs, we need to protect both their C2 and data transmission links against jamming, as well as consider counters to physical threats.

These activities all take time, money, thoroughness, and patience. They also take a family of UAVs, just as more than one aircraft is needed to meet multiple mission requirements. Any one program's fortunes may fluctuate from year to year, but overall we have made substantial progress. *Pioneer, Hunter* and *Predator* are flying routinely. *Outrider* is defining its capabilities. The HAE UAVs should be airborne shortly. ***A promising future for ISR is just around the corner — to support both the warfighter and our broader national objectives.***

UAVs are a key element within the concept of Information Dominance. As an office of the Secretary of Defense, the DARO's first responsibility is to develop and maintain the DoD's integrated airborne reconnaissance architecture as a framework for the development and acquisition of improved airborne reconnaissance capabilities.

Supporting the Warfighter



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DOCUMENT 2

Unmanned Aerial Vehicles and Weapons of Mass Destruction: A Lethal Combination?

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AIR UNIVERSITY

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Contents

Illustrations

Abstract

This study analyzes the characteristics and capabilities of unmanned aerial vehicles (UAV) to determine their capability to carry weapons of mass destruction (WMD). The author presents an overview of the various forms of WMD—chemical, biological, and nuclear weapons. The objective is to review the characteristics of both UAVs and WMD to determine if they are capable of being used together as an effective weapon. The result indicates that there is great potential for the use of UAVs as delivery systems for WMD, particularly by developing nations and nonstate actors such as terrorist groups who may not have the technical capability to employ other means. The potential exists for the proliferation of both UAVs and WMD to become widespread and thus a major security concern. There is no clear solution to this problem; however, actions including bringing the issue to the forefront, strengthening export and arms controls, deterrence, and defense will have a synergistic effect that will help mitigate this threat.

About the Author

Lt Col (Col-select) Jeffrey N. Renehan is a master missileer who received his commission in 1981 through the Reserve Officer Training Corps and in 1982 received his Minuteman intercontinental ballistic missile (ICBM) initial combat crew qualification training. He has a bachelor's degree in business from the University of Colorado and a master of business administration from the University of South Dakota. During his initial tour, he served as an ICBM operations combat crew deputy, flight commander deputy, instructor deputy, and commander. He also served as an emergency war order instructor and as the 44th Strategic Missile Wing executive officer. Next, he was selected for the Strategic Air Command's ICBM operational test launch program, known as Top Hand. Two years later, he was assigned to the secretary of the Air Force's ICBM modernization acquisition office in the Pentagon where he served as a program element monitor and congressional liaison officer. In 1992 he was selected for a joint duty assignment at the Department of State as the space and missile policy advisor to the assistant secretary of state for political military affairs. In June 1996 he graduated from the School of Advanced Airpower Studies and was assigned to the 576th Test Squadron as the squadron commander designee.

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Chapter 1

Introduction

Weapons of mass destruction—nuclear, biological, and chemical—along with the systems that deliver them, pose a major threat to our security and that of our allies and other friendly nations. Thus, a key part of our strategy is to seek to stem the proliferation of such weapons and to develop an effective capability to deal with these threats.

—President William J. Clinton
A National Security Strategy of Engagement and Enlargement

The cold war may be over, but the effects caused by the change from a bipolar global geopolitical situation to a multipolar (or unipolar) situation may be more ominous than once imagined. Regional stability, long a concern of the United States (US), has now become an increasingly prevalent problem. The break up of the former Soviet Union has spurred the creation of many new nations and has reduced the degree of superpower control over other third world states paving the way for increased political, social, and economic strife. One of the biggest concerns of the current US administration is the proliferation of weapons of mass destruction (WMD) and the systems that deliver them.

WMD delivery systems often receive less attention than do the weapons themselves. Technology in this area has evolved to the point that effective WMD delivery systems are not limited to just ballistic missiles and aircraft. Much smaller, more accurate, and less expensive unmanned systems are being developed everyday. One of the most potentially important new categories of delivery systems is unmanned air vehicles (UAV). The question specifically is, Are UAVs adaptable as WMD delivery vehicles? If so, what are the implications for international stability and defense? What options are available for combating their proliferation to countries of concern? If they do not present a threat in this capacity, is there a danger of overreacting to a misperceived threat and thus expending needless time, resources, and money?

WMD and their associated delivery systems have been a global concern for many years. Many believe that this concern began with the development of the first nuclear weapon by the United States in the Manhattan project. It really starts much earlier. The conventional definition of WMD includes chemical and biological weapons in addition to nuclear ones. Some of the earliest recorded uses of biological warfare occurred in the fourteenth century, when the Mongols placed plague-infected cadavers on their catapults and

flung them into the walled city of Caffa. Mustard gas and other chemical agents were used in the trenches of World War I and were delivered by a number of means, including artillery and airplanes. Additionally, Iran and Iraq used chemical weapons during their conflict in the 1980s.[1] During the 1991 Gulf War, there was great concern that Iraq might have the capability to deliver chemical, biological, and even nuclear weapons with Scud missiles. WMD have been available for many years, their deployment just limited by the delivery systems available at the time. Consequently, the combination of more efficient WMD and more effective delivery systems have become an area of great concern.

The principal Western response to this problem was the formation of the missile technology control regime (MTCR) in 1987. At that time, seven industrialized nations (the United States, Germany, France, Italy, Japan, the U.K., and Canada) identified a need to prevent the spread of delivery systems for WMD. The MTCR Guidelines state that "the purpose of these guidelines is to limit the risks of proliferation of weapons of mass destruction (i.e., nuclear, chemical, and biological weapons), by controlling transfers that could make a contribution to delivery systems (other than manned aircraft) for such weapons."[2] Because the MTCR focuses on the delivery systems for WMD, not the weapons themselves, it differs from other regimes and treaties which deal with the weapons themselves, such as, the Nuclear Nonproliferation Treaty (NPT) and the Chemical Weapons Convention (CWC). "Delivery systems" in the case of the MTCR, refers to all unmanned systems, including ballistic missiles, cruise missiles, and, less prominently, UAVs and drones.

UAVs are defined as powered aerial vehicles sustained in flight by aerodynamic lift over most of their flight path and guided without an onboard crew. They may be expendable or recoverable and can fly autonomously (via an inertial navigation system) or be piloted remotely.[3] Remotely piloted vehicles (RPV) are usually considered a subset of UAVs. They are unmanned aircraft capable of being controlled from a distant location through a communications link.[4] While both are normally designed to be recoverable and nonautonomous, they can be adapted for expendable and autonomous use. This is done by modifying the software and guidance equipment to fly a one-way mission with autonomous guidance to the terminal area.

Historically, the greatest use of UAVs has been made in the areas of intelligence gathering, surveillance, and battle damage assessment (BDA), where they allow armed forces to avoid placing pilots at risk. They have also been used to gather nonmilitary information in environments that are hazardous to human beings. For example, B-17 bombers were adapted to fly by remote control during the Bikini Atoll nuclear bomb tests.[5] The Israelis have also used UAVs extensively for reconnaissance purposes. During the Gulf War, the coalition allies used them for intelligence and BDA purposes. In fact, the Pioneer UAV was praised as "the single most valuable intelligence collector" in the war against Iraq.[6] They have proved to be extremely reliable and have had high mission completion rates. During the Gulf War, only one UAV was lost in more than 300 missions.[7] Finally, they have been

successfully used in Bosnia as airborne surveillance platforms. Their small size and low altitude capability make them extremely hard to locate and destroy. To date, after hundreds of missions into hostile territory, only two Predator UAVs have been lost.[8]

This study examines the potential of UAVs to be WMD delivery vehicles and their inherent advantages that may make them attractive to developing nations as they build their arsenals. Due to the broad nature of this topic, this study focuses on the subject of the potential delivery of WMD with UAVs by underdeveloped and third world nations. However, the findings are equally applicable to nonstate actors (such as terrorist groups) and more advanced countries.

Chapter 2 provides basic, unclassified information about the characteristics and capabilities of some of the UAVs that are currently in development and production. It also discusses the capabilities which make them particularly suitable as WMD carriers. Chapter 3 presents a basic overview of chemical, biological, and nuclear weapons. It demonstrates that the size, weight, and other characteristics of these weapons make them potentially suitable for use with UAVs. For some WMD, UAVs may even be the ideal delivery system.

Chapter 4 presents a scenario that illustrates how UAVs and WMD could be married into a complete delivery system by a developing nation. Chapter 5 examines the nature and extent of the strategic threat posed by UAV-delivered WMD. The evidence presented in chapters 2 and 3 shows that these systems are capable of being married together to form effective WMD delivery systems. This raises some interesting problems for the international nonproliferation community. In light of this, the final chapter looks at the policy alternatives available to the United States to prevent widespread dissemination of these systems.

Notes

1. Randall J. Larsen and Robert P. Kadlec, *Bio War: A Threat to America's Current Deployable Forces* (Arlington, Va.: Aerospace Education Foundation and the Air Force National Defense Fellows, April 1995), 4–5.
2. *Missile Technology Control Regime Guidelines* (Washington, D.C.: Department of State, PM/CBM, 1995), 1.
3. Air Chief Marshal Sir Michael Armitage, *Unmanned Aircraft* (London: Brassey's Defence Publishers, 1988), xi.
4. Ibid., xi–xii.
5. David R. Mets, "Eglin and the Dawn of the Nuclear Age," *Eglin Eagle*, 26 April 1985, 8.
6. Lt Gen Walter Boomer, USMC, Marine Corps Central Command Element Headquarters (MARCENT) papers.
7. *Unmanned Aerial Vehicles 1994 Master Plan* (Washington, D.C.: Government Printing Office, 31 May 1994), 3–9.
8. John G. Roos, "That F-Word," *Armed Forces Journal International*, September 1995, 19.

Chapter 2

Unmanned Aerial Vehicle and Remotely Piloted Vehicle Technologies

Small, survivable, "damned elusive" and increasingly smart, the unmanned aircraft is enjoying a resurgence of interest in its varied capabilities on the modern battlefield.

—Kenneth Munson
Air International

Unmanned aerial vehicles are not new. The technology to develop and employ them has been available for many years. However, recent technological developments have combined to make UAVs smaller, faster, more accurate, more reliable, and generally more capable than they have been in the past. In order to begin answering the question of whether UAVs could effectively deliver WMD, this chapter presents an overview of the capabilities of some typical UAVs. It begins by providing some definitions as a common starting point for discussion and then presents examples of some current and projected aircraft.

Definitions

Different types of UAVs are known by many names, often leading to unnecessary confusion. The following definitions will be used in the current study.[1]

> Unmanned aerial vehicle (UAV): An aerial vehicle that has no onboard pilot and is capable of preprogrammed autonomous operation or operations received from a human operator located some distance (either on the ground or on a seaborne or airborne platform) from the vehicle.
>
> Remotely piloted vehicle (RPV): Usually considered a subset of UAVs, RPVs are aerial vehicles that do not have an onboard pilot and are capable of receiving continuous or intermittent commands from a human operator located at a ground, seaborne, or airborne station some distance from the vehicle.
>
> Drone: An aerial vehicle that has no onboard pilot and is preprogrammed prior to launch to accomplish a set of functions with no further human intervention or command. The drone may use onboard sensors to autonomously make mission adjustments. Drones are usually designed for such uses as expendable targets with relatively short operating distances and loiter times.
>
> Guided missile: An unmanned aerial vehicle whose trajectory can be altered by external or internal mechanisms (i.e., seeker heads, laser designators, or fly-by-wire systems).
>
> Cruise missile: A guided unmanned aerial vehicle whose flight path is executed at approximately constant velocity. The cruise missile seeks to complete its preprogrammed mission, but may alter its course based upon onboard sensor information.

There are similarities among all of these definitions. Historically, UAVs have been developed for use as intelligence gathering and battlefield surveillance devices. Their designs have emphasized the needs to be affordable, portable, easily launched, easily maintained, reliable, and recoverable. The last characteristic, recoverability, further sets them apart from other unmanned vehicles. The key issue for their use as WMD delivery vehicles is that the same capabilities that make them good surveillance tools also makes them very well suited to a strike role.

Unmanned Aerial Vehicle Examples

The key point to keep in mind during this review of UAV technology is not the details of the particular systems per se, but the unique characteristics they display and their potential to carry WMD. Chapter 3 provides a review of salient WMD characteristics and by combining the information provided in both chapters, the reader will gain some appreciation of the possibility of marrying the two for WMD delivery purposes.

Space does not allow for a review of every UAV on the market today. However, the following examples will provide an overview of the basic characteristics of a range of models from small ones with low payload capabilities through the higher end types which approach cruise missile characteristics.

For a synopsis of the capabilities of the UAVs highlighted in this chapter, see table 1.[2]

Table 1

Unmanned Aerial Vehicles

UAV	*Launch Weight*	*Payload*	*Range*	*Loiter Time*	*Guidance*	*Dimensions**	*Cost Per Vehicle*
Exdrone	40.5 kg	11 kg	120 km	2.5 hrs	Manual/Auto	1.6 m x 2.5 m	$20 k
Pioneer	200 kg	50 kg	185 km	6–9 hrs	Manual/Auto	4.3 m x 5.1 m	$660 k
Hunter	667 kg	143 kg	150 km	14 hrs	Manual/Auto	7 m x 9 m	$1.2 M
Delilah	180 kg	55 kg	400 km	5 hrs	Manual/Auto	2.7 m x 1.5 m	about $200 k
Scarab	1,077 kg	132 kg	3,150 km	N/A	Manual/Auto	6.2 m x 3.4 m	N/A
Model 410	817 kg	227 kg	2,000 km	10 hrs	Manual/Auto	6.6 m x 9.6 m	N/A
Tier II Plus	10,394 kg	907 kg	5,000 km	42 hrs	Manual/Auto	N/A	$10 M
Tier III Minus	N/A	230 kg	800 km	N/A	Manual/Auto	N/A	$10 M

Source: Information in this table was derived from a combination of "All the Worlds' Unmanned Air Vehicles," *Interavia Aerospace Review*, December 1991, 47; "Dossier," *International Defense Review*, May 1995, 84; and Kenneth Munson, "Pilotless Pimpernels," *Air International*, February 1992, 88.

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*The dimensions given are length x wingspan. Cost data are approximate estimates.

The Exdrone UAV is a small, delta-wing vehicle designed by Battlefield Air Interdiction (BAI) Aerosystems for the US Marine Corps and is used for reconnaissance on the battlefield. It is powered by a one-cylinder, two-cycle internal combustion engine which produces about 5.2 horsepower, giving it a top speed of about 185 kilometers (km) per hour. The Exdrone's ceiling is about 10,000 feet.[3]

The Pioneer UAV is also a small vehicle designed for surveillance and reconnaissance. It is of typical tailed aircraft design, manufactured by Israeli Aircraft Industries and is currently in service with the US Navy. It is powered by a two-cylinder, two-stroke, engine that produces about 28 horsepower which allows a top speed of about 170 km per hour. The Pioneer's ceiling is about 15,000 feet.[4]

The Pioneer demonstrated its unique capabilities during the Gulf War. US forces flew it on more than 300 combat missions over hostile territory. Only one vehicle was shot down, and three others were hit by ground fire but were recovered.[5] This was a graphic demonstration of UAV penetration and survivability characteristics.

The intended follow-on to the Pioneer UAV was the Hunter, designed and produced by Israeli Aircraft Industries and TRW for surveillance and target acquisition missions. It is powered by two Teledyne Continental GR-18 rotary piston engines that produce a total of about 45 horsepower which allows a top speed of about 225 km per hour and a ceiling of about 19,000 feet. The Hunter program has been canceled due to logistic supportability and propulsion problems. However, it still is an excellent example of the capabilities of UAVs and how technology is evolving to increase their capabilities.[6]

The Delilah UAV is also produced by Israeli Aircraft Industries. It is an outgrowth of earlier Israeli adaptations of the Northrop Chukar, which was used as an aerial target drone. It is a more advanced design than the UAVs discussed above and is powered by one Noel Penny NPT 151-4 turbojet engine rated at 165 pounds of thrust, which allows speeds of up to 900 km per hour. The Delilah's ceiling is approximately 32,000 feet.[7] A unique characteristic of the Delilah is that it is designed to be nonrecoverable. The flight control system is a preprogrammed inertial navigation system with a global positioning system (GPS) update that is purely autonomous, in fact, it is described as a "fire and forget" system.

The next two UAV systems are both produced by the Teledyne Ryan Corporation. The first is the BQM-145A, the Scarab. It was developed in the 1980s and was sold to Egypt as a ground-launched tactical reconnaissance vehicle. It is powered by one Teledyne CAE 373-8C turbojet engine rated at 970 pounds of thrust which gives it a maximum speed of over 845 kilometers per hour. The Scarab's ceiling is approximately 43,000 feet.[8]

The second Teledyne Ryan UAV is the Model 410. Large enough to carry full-size, up to 227 kilograms (kg), instead of miniaturized payloads. It was designed for long-range or long-endurance missions, and it was first flown on 27 May 1988 with a man on board. Its first unmanned flight was in 1992. It is powered by one Textron Lycoming TIO-320-C1B flat-four piston engine rated

at 160 horsepower which allows a maximum speed of over 322 km per hour. The Model 410's ceiling is approximately 30,000 feet.[9]

UAV technology, like most technology, is not stagnant but is continuing to evolve. One segment of the next generation of UAVs that US manufacturers are developing for the US Air Force is the Tier II/III family of endurance model UAVs which will provide significant new reconnaissance capability for the US military.[10]

The Tier II Plus program, the high altitude endurance UAV, is currently being developed to provide a high endurance vehicle capable of continuous, all weather surveillance. This vehicle is capable of operating to ranges in excess of 4,500 km. It has a ceiling of 65,000 feet, a top speed of over 500 km per hour, and a payload of over 600 kg. It, too, is capable of fully autonomous flight and is planned to cost less than $10 million per aircraft.[11]

Finally, the Tier III Minus program, the low observable high altitude endurance UAV, further demonstrates how evolving technology is being incorporated into making them more survivable and capable. This vehicle, nicknamed Dark Star, is projected to have a range of approximately 800 km, a ceiling of more than 40,000 feet, a top speed of about 400 kilometers per hour, and a payload of approximately 230 kg. The key feature of the Tier III Minus program is its use of low observable or stealth technology. This gives it much greater penetration and survivability characteristics than equivalent nonstealthy systems. Finally, as with its sister Tier II programs, it will be capable of fully autonomous flight. The program is currently in source selection so cost data is not available at this time.[12]

In addition to complete systems available for sale, another way to obtain a UAV system is to build it by obtaining the major subsystems and then assembling them. The nominal cost of materials for a small UAV capable of autonomous flight and equipped with a commercially available agricultural spraying device is less than $90,000.[13] Although much less sophisticated, a vehicle of this type would have roughly the same size and range/payload characteristics as the Pioneer system. Home-built aircraft companies provide access to advanced materials, equipment, and guidance technology. For instance, a basic, accurate, autonomous navigation and control system with a GPS update can be assembled for less than $25,000.[14] The other subsystems, such as the airframe and the engine, make up the remainder of the cost. There are currently more than 20 countries and five international consortia that produce UAVs and their components.[15] The MTCR controls the export of these parts, if they are destined to be used in a system that will carry WMD. However, discovering this intent is very difficult. Once a state or other actor obtains these parts, constructing a UAV is about as complicated as making a home-built airplane.[16]

The purpose of this study was not to present an all-encompassing encyclopedia of available UAV technology, but rather to show the range of UAVs that are being produced around the world today. Technology is evolving in such a way that these vehicles are steadily becoming more capable and much less expensive.

This also makes them increasingly adaptable to missions other than the current applications of surveillance and reconnaissance.

Global Positioning System

GPS has been mentioned throughout this chapter in discussing accurate guidance systems for UAVs. Unclassified sources show that GPS has the capability to provide remarkable accuracy. There are two types of signals provided by the GPS satellites. Authorized users with cryptographic equipment, keys, and specially equipped receivers use the precise positioning system (PPS). The United States and allied military, certain US government agencies, and selected civil users specifically approved by the US government can use the PPS which provides accuracy of less than 10 meters. Civil users worldwide use the standard positioning system (SPS). This system is intentionally degraded by the Department of Defense by the use of a code called Selective Availability. However, accuracy in this mode is still less than 100 meters.

There is a technique to increase the accuracy of systems using either GPS system called Differential GPS. This technique corrects bias errors at the mobile receiver with measured bias errors at a known position. A reference receiver, or base station, computes corrections for each satellite signal. This is a complicated procedure and requires a mobile GPS receiver that can receive the bias changes via radio link and process in-flight computations and course corrections.

Costs vary depending on capabilities. Small civil SPS receivers can be purchased for less than $500. Receivers capable of using differential corrections cost between $1,000 and $5,000. Receivers that can act as Differential GPS reference receivers (computing and providing correction data) cost between $5,000 and $40,000, depending on their capabilities.[17]

Conclusion

UAVs are suitable for a variety of roles, including strike missions, and are capable of carrying a wide range of payloads. Again, the models presented are only a representative sample and many others, produced all over the world, are available for general purchase.

However, the basic technology and concept of UAVs are not new or unique ideas. The question arises of why UAVs haven't yet been employed more widely in roles such as strike missions. The answer is twofold. First, technology, especially navigation technology, has evolved, and continues to evolve, to such an extent that UAVs are now far more capable than ever before. The models presented are good examples of this. A second reason is that technically advanced countries have the means and the technology to choose advanced systems like ballistic missiles or cruise missiles instead of UAVs.[18]

However, with UAV capabilities improving and costs decreasing, UAVs could be coming into their own as an alternative to more advanced systems. A few years ago only a few companies such as Teledyne Ryan Corporation and Israeli Aircraft Industries showed interest in UAVs, but now companies are so certain of the future of UAVs that many are entering the market.[19] Capabilities such as increased range and payload, autonomous air vehicle avionics, precision navigation systems, long loiter times, hypervelocity, portability, and transportability are making UAVs and RPVs particularly attractive.[20] In fact, low altitude, unmanned vehicles have particular significance as force multipliers for ground attack, in addition to traditional roles of battlefield reconnaissance. Finally, as US experiences hunting Scuds in the Gulf War showed, it is almost impossible to locate and destroy a small mobile system that is covertly deployed. In fact, the Gulf War intelligence community never could furnish reliable information on the number and location of Iraq's Scud launchers. This forced an intensive anti-Scud campaign that seriously reduced the number of Scud firings, but never totally ended them.[21] UAVs should be even harder to find than mobile Scuds were, given their smaller size and reduced maintenance and support requirements.

This chapter shows that UAVs are very diverse platforms, capable of a myriad of missions. By taking advantage of evolving technology, manufacturers have turned simple target drones into remotely piloted and/or autonomous aerial vehicles with exceptional capabilities. To use UAVs for strike missions, the next question is what types of weapons could be effectively married to UAVs in order to provide an effective weapon. The next chapter presents a review of the unique characteristics of one possible answer: weapons of mass destruction—chemical, biological, and nuclear weapons.

Notes

1. Will Davis, *The Human Role in Future Unmanned Vehicle Systems* (Air Force Systems Command, Office of the Deputy for Development Planning, December 1988), 3.

2. Approximate costs—in table 1 and on all UAVs presented in this chapter—are unclassified estimates and were obtained from telephone interviews with the Department of Defense, Program Executive Office, Cruise Missile Project, and Unmanned Aerial Vehicle Joint Project. Conclusions drawn from this information are my own and do not reflect the opinions or policy of this office.

3. "All the Worlds' Unmanned Air Vehicles," *Interavia Aerospace Review*, December 1991, 47.

4. Specifics on the Pioneer system come from a combination of "All the Worlds' Unmanned Air Vehicles," 47; "Dossier," *International Defense Review*, May 1995, 84; and Kenneth Munson, "Pilotless Pimpernels," *Air International*, February 1992, 88.

5. *Unmanned Aerial Vehicles 1994 Master Plan* (Washington, D.C.: Government Printing Office, 31 May 1994), 3–5.

6. Specifics on the Hunter system come from a combination of "All the Worlds' Unmanned Air Vehicles," 46; "Dossier," *International Defense Review*, May 1995, 88; and Munson, 88.

7. Munson, 88.

8. Specifics on the Scarab system come from a combination of "All the Worlds' Unmanned Air Vehicles," 47; "Dossier," 94; and Munson, 89.

9. Specifics on the Teledyne Model 410 system come from a combination of "All the Worlds' Unmanned Air Vehicles," 47; "Dossier," 93; and Munson, 89.

10. John Entzminger, "Acquiring Affordable UAVs," *Journal of Electronic Defense*, January 1995, 35.

11. Ibid., 35–39.

12. Data on the Tier III Minus program was obtained from telephone interviews with the Department of Defense, Program Executive Office, Cruise Missile Project, and Unmanned Aerial Vehicle Joint Project. Conclusions drawn from this information are my own and do not reflect the opinions or policy of this office.

13. The author conducted an informal industry survey of a number of UAV kit manufacturers, agricultural supply companies, and GPS producers. The costs presented here are a result of this survey and are very rough estimates. Costs could vary considerably, depending on the characteristics and capabilities that are sought.

14. Ibid.

15. J. R. Wilson, "Suddenly Everyone Wants a UAV," *Interavia Aerospace Review*, December 1991, 46–47.

16. Construction techniques and ease of assembly were obtained from the informal survey.

17. All GPS information was obtained from the University of Texas, Department of Engineering, on the World Wide Web at site http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html.

18. Col Harald G. Hermes, USAF, *The Nonnuclear Cruise Missile—Low Cost Force Augmentor* (Maxwell AFB, Ala.: Air War College, 1980), 214–16. For example, the US Tomahawk missile (TLAM) is 18 feet long and 20 inches in diameter. It is powered by a small turbofan engine which produces ranges in excess of 1,500 miles and speeds of 550 miles per hour. Navigation is performed with an inertial navigation system updated periodically with the Terrain Contour Matching (TERCOM) system. This system compares terrain gradients observed by the TLAM's radar altimeter to those stored in its computer. In the terminal phase, accuracy at the target is further improved using Scene Matching Area Correlator (SMAC). SMAC compares a stored photo of the target with one obtained in flight. Finally, the TLAM's payload capability allows it to carry a variety of loads and makes it a very flexible weapons delivery platform.

19. Wilson, 43.

20. Davis, 63–64.

21. Richard P. Hallion, *Storm over Iraq, Air Power in the Gulf War* (Washington and London: Smithsonian Institution Press, 1992), 245.

Chapter 3

Weapons of Mass Destruction

I, William J. Clinton, President of the United States of America, find that the proliferation of nuclear, biological, and chemical weapons ("weapons of mass destruction") and the means of delivering such weapons, constitutes an unusual and extraordinary threat to the national security, foreign policy, and economy of the United States, and hereby declare a national emergency to deal with that threat.

—*Presidential Executive Order*
14 November 1994

Few international dangers confronting the United States have more serious and far-reaching implications for national security and worldwide stability than the proliferation of weapons of mass destruction.[1] WMD include nuclear, chemical, and biological weapons. The proliferation of WMD is a global problem that reaches across national, geographic, political, cultural, and social boundaries. It also involves all types of countries, including those led by reactionary and unstable regimes. For example, North Korea, Libya, Syria, Iran, and Iraq are all identified as actively pursuing WMD programs.[2]

While the proliferation of these types of weapons is clearly a problem, an even greater concern is if and when someone will decide to use them. For example, the episode in Japan in which a terrorist group released the nerve agent Sarin into a crowded subway elicited worldwide shock and concern.[3]

Controlling the spread of WMD is no simple matter. Many of the technologies associated with WMD programs (especially the nonnuclear ones) have legitimate civilian or military applications unrelated to WMD. This makes it difficult to restrict trade in those technologies because developing nations have legitimate needs for them. For example, chemicals used to make nerve agents are also used to make plastics and to process foodstuffs. A modern pharmaceutical industry can produce biological warfare (BW) agents as easily as vaccines and antibiotics, using the same equipment and raw materials. Additionally, as potential proliferation countries' economies improve and their industrial bases mature, their dependence on foreign countries to provide the technologies necessary for WMD development and production decline, making early detection and interdiction of new programs increasingly difficult.[4]

This chapter presents an unclassified overview of chemical, biological, and nuclear weapons focusing especially on their potential deliverability by UAVs. It is not meant to be all inclusive, but simply to give the reader an

appreciation of the scope, characteristics, and destructive capabilities of these weapons.

Chemical Weapons

Chemical warfare (CW) is the military use of toxic substances whose effects on exposed personnel result in incapacitation or death. The impact of chemical effects as opposed to physical effects (such as blast and heat) distinguishes chemical weapons from conventional weapons. Optimally, the chosen delivery system disseminates the chemical agent as a cloud of fine droplets, known as an aerosol. This permits the highly toxic agent to cover a relatively large amount of territory evenly and efficiently.[5]

History

Modern chemical warfare began in 1915, when the Germans used chlorine gas, a choking agent, on French troops. Allied forces soon responded in kind, which resulted in an escalation of chemical warfare by both sides that lasted until the end of the war. By the time of the signing of the armistice in November 1918, more than one million people had been injured by chemical weapons and nearly 100,000 had been killed. Chemical weapons were also used sporadically after World War I (by Italy in Ethiopia in 1937 and the Egyptians in Yemen during the mid-1960s), however, large scale use of chemical weapons did not resume until Iraq used them against Iran in 1983.[6] Even though a precedent of sorts had been set in World War I, chemical weapons were not used in World War II.

Chemical Warfare Agents

Chemical agents are classified in a number of ways. They can be either lethal or nonlethal, and there is not always a clear distinction between the two. Lethal agents, like Sarin, are primarily designed to cause death on the battlefield, although sublethal doses can incapacitate. Nonlethal agents, like tear gas, are primarily designed to incapacitate or injure (although large doses can kill) and are used for purposes such as crowd control.[7] Both kinds are categorized by chemical weapons experts according to the following characteristics.

Mode of action indicates how the agent affects living things. When used as a chemical weapon, the most useful routes of exposure are passive ones, such as inhalation and percutaneous means. Chemicals using the latter damage or enter the body through the skin, eyes, or mucous membranes. Percutaneous poisons are classified according to whether they act orally (by damaging the digestive system or passing into the bloodstream when swallowed) or intravenously (by passing directly into the bloodstream).[8]

Speed of action refers to the delay between exposure and effect. Rapid-acting agents can cause symptoms to appear almost instantaneously

and may cause fatalities in as little as a few minutes. With slow-acting agents, symptoms can take anywhere from hours to days to appear, and it may take weeks or months for fatalities to occur. As a general rule, higher doses increase the speed of action.[9]

Toxicity measures the quantity of a substance required to achieve a desired effect. For instance, 70 milligrams (mg) of the nerve agent Sarin per cubic meter of air will kill 50 percent of a human population breathing this mixture. Just 10 mg of the nerve agent VX on the skin will kill the average adult male. One gallon of VX contains 382,000 such doses. By definition, if the VX is applied evenly at this dosage, 50 percent or 191,000 people will die, and the other 191,000 will become seriously ill. Exposure rates of this kind are impractical on the battlefield, but this does give a good example of how highly toxic some agents can be.[10]

Persistency measures the time an agent remains a hazard in the target area. Nonpersistent agents are relatively volatile and evaporate quickly, usually within a few minutes to an hour. Semipersistent agents usually linger for several hours to a day. Persistent agents, which are usually rather thick and oily, can last for several days to a few weeks. In general, the length of time an agent remains a hazard varies widely according to the environment and meteorological conditions. For instance, chemical agents will dissipate more quickly when exposed to high temperatures, wind, rain, and unstable atmospheric conditions.[11]

State refers to the physical form of an agent. Agents can be solid, liquid, or gas—however, most are liquids. The term *gas* is actually something of a misnomer, stemming from the fact that most chemical agents are disseminated as aerosol or vapor clouds which resemble gas clouds.[12]

Classes of Agents

Chemical agents are commonly classified by the type of effect they have on the human body. The most common classes are choking agents, blood agents, blister agents, G- and V-series nerve agents, nonlethal agents, vomiting agents, and psychochemicals. Table 2 provides an overview of these agents, their persistency, and rate of action.

In general, choking agents, due to their corrosive effect on the respiratory system, result in pulmonary edema, filling the lungs with fluid, and choking the victim. Blood agents are absorbed into the body primarily by breathing and prevent the normal utilization of oxygen by the cells and cause rapid damage to body tissues. Blister agents are primarily used to cause medical casualties. They blister the skin and damage the eyes and lungs. G-series nerve agents act rapidly and, in sufficient doses, cause paralysis of the respiratory musculature and subsequent death. V-series nerve agents are similar to, but more advanced than, G-series agents, and tend to be more toxic and persistent. Nonlethal agents include tear gasses (which are highly irritating, particularly to the eyes and respiratory tract, and cause extreme discomfort), vomiting agents (which in addition to causing vomiting may also

Table 2

Chemical Warfare Agents

Agent Class	*Agent Name*	*Symbol*	*Persistency*	*Rate of Action*	*Toxicity*
Nerve	Tabun	GA	Low	Very Rapid	Lethal
	Sarin	GB	Low	Very Rapid	Lethal
	Soman	GD	Moderate	Very Rapid	Lethal
	GF	GF	Moderate	Very Rapid	Lethal
	VX	VX	Very High	Rapid	Lethal
Blister	Sulfur Mustard	H, HD	Very High	Delayed	Nonlethal
	Nitrogen Mustard	HN-1	High	Delayed	Nonlethal
		HN-2	Moderate	Delayed	Nonlethal
		HN-3	Very High	Delayed	Nonlethal
	Phosgene Oxime	CX	Low	Immediate	Nonlethal
	Lewisite	L	High	Rapid	Nonlethal
	Phenyldichloroarsine	PD	Low-Moderate	Rapid	Nonlethal
	Ethyldichloroarsine	ED	Moderate	Delayed	Nonlethal
	Methyldichloroarsine	MD	Low	Rapid	Nonlethal
Choking	Phosgene	CG	Low	Delayed	Lethal
	Diphosgene	DP	Low	Variable	Lethal
Blood	Hydrogen Cyanide	AC	Low	Rapid	Lethal
	Cyanogen Chloride	CK	Low	Rapid	Lethal
	Arsine	SA	Low	Delayed	Lethal
Riot Control (vomiting)	Diphenylchloroarsine	DA	Low	Rapid	Nonlethal
	Diphenylcyanoarsine	DC	Low	Rapid	Nonlethal
	Adamsite	DM	Low	Rapid	Nonlethal
Riot Control (Tear Gas)	Chloroacetophenone	CN	Low	Immediate	Nonlethal
	Chloropicrin	PS	Low–High	Immediate	Nonlethal
	Bromobenzylidene	CA	Moderate–Very High	Immediate	Nonlethal
	O-Chlorobenzylidene Malononitrile	CS	Low–High	Immediate	Nonlethal
Psycho-chemical	3-Quinuclidinyl Benzilate	BZ	High	Delayed	Nonlethal

Source: *The Chemical and Biological Warfare Threat* (Washington, D.C.: Government Printing Office, April 1995), 8.

irritate the eyes and respiratory system), and psychochemicals (which alter the nervous system, thereby causing visual and aural hallucinations, a sense of unreality, and changes in thought processes and behavior).[13]

There are many ways to disseminate chemical agents. The most common are munitions that are fired or dropped on a target by artillery or aircraft. These munitions normally contain burster charges surrounded by the chemical agent. The burster ruptures the munition and causes the chemical agent to spread as a stream or cloud of small droplets.[14] This system is limited by the size of the munition and the carrying capability of the systems used to deliver it.

However, a more effective way to disseminate these agents is through the use of aerosol generators which allow for a more controlled release. A spray

tank can be used to disseminate agents from aircraft, just as crop dusters are used to spread insecticides. Such a system provides the capability to spread the agent in a fine aerosol form over a large, relatively controlled target area. Further, it lends itself to the use of UAVs or manned aircraft as the delivery system because of their capability to loiter over a target and accurately place the agent.[15]

Production

An inherent advantage of chemical weapons is that they are relatively simple to produce. Many are based on technology that is 80 years old or older, putting them well within the reach of virtually any developing nation that wants them. Additionally, the production of chemical agents is much like that of chemicals used for legitimate industrial and agricultural purposes. Both chemical agents and commercial chemicals involve the use of standard chemical processing equipment, including reactor vessels, in which production actually occurs; distillation columns and filters, where compounds are separated or purified; heat exchangers, to control temperature; and various pumps, pipes, valves, and other items that control the movement of chemicals throughout the plant.[16]

Actions are being taken to control export of this equipment when intelligence sources show that it is destined for use in chemical weapons programs by existing export control regimes such as the Australia Group (AG).[17] The synergistic efforts of these regimes with the Chemical Weapons Convention (CWC) and the Biological Weapons Convention (BWC) have combined to make it very difficult (but not impossible) for countries of concern to obtain the necessary items to develop active chemical weapons programs.

Biological Weapons

While chemical weapons programs can be developed with relatively low capital investment and with dual use technology, chemical weapons are difficult to stockpile and large amounts are required to pose a serious threat to well-trained and well-equipped troops.[18] According to Gen Colin L. Powell, "It is for these reasons, among others, that many people believe a more significant threat is that of biological weapons. The one that scares me to death, perhaps even more so than tactical nuclear weapons, and the one we have the least capability against is biological weapons."[19]

BW agents are inherently more toxic than CW nerve agents of comparable weight. Additionally, they are potentially more effective because most of them are naturally occurring pathogens (like bacteria and viruses) which are self-replicating and have specific physiologically targeted effects. This is in contrast to chemical agents, which tend to disrupt physiological pathways in a more general way.[20]

In 1995 as many as 100 nations were estimated to have the technological capability to develop biological weapons programs.[21] This, combined with the fact that biological weapons are attractive for terrorist use, make them a major security concern today.

History

Some of the earliest recorded uses of biological warfare occurred in the fourteenth century. During the siege of the Crimean seaport of Caffa, the Mongols placed plague-infected cadavers on catapults and flung them into the walled city. The cadavers proved more effective than any other projectiles. The plague spread throughout the city and the Genoese inhabitants fled. Several medical historians even believe that the "Black Death" that subsequently spread across Europe, killing nearly one-third of the European population, actually began on the catapults at the siege of Caffa.[22]

The first modern use of biological agents probably occurred in World War I. The Germans were accused of using cholera in Italy and the plague in Saint Petersburg in 1915. While there was no widespread use of these agents in World War II, every major combatant had a BW program. In fact, by the end of the war, the United States had developed large scale research, development, production, and weaponization facilities. These weapons included both antipersonnel and anticrop diseases.[23]

The United States continued BW research and development efforts until 1969, when President Richard M. Nixon announced a unilateral ban on the use of lethal biological agents and weapons. All further biological research was limited to defensive measures such as immunization, detection, and safety. In 1975 President Gerald R. Ford signed the Biological Weapons Convention prohibiting the development, production, and stockpiling of bacteriological and toxin weapons. However, BW programs continued or were subsequently developed by countries such as North Korea, Libya, Syria, Iran, and Iraq.[24]

Agents

There are approximately 160 known disease-causing species that affect human beings. Of these, more than 60 are discussed in unclassified literature as potential BW agents.[25] Agents that have been widely recognized as having military utility are determined to be suitable based on four characteristics. First is *infectivity or virulence*—a small dose should produce a predictable response such as death or incapacitation. Second is *producibility*—how easily they can be produced and stored. Third is *stability*—the resistance an agent has to the effects of ultraviolet light, heat, cold, and other environmental factors. Fourth is *ability to disseminate*—how easy an agent is to package in a form that can be used effectively in a weapon.[26]

Agents can be divided into two main categories: pathogens and toxins. Pathogens are defined as organisms that cause disease in man and may be grown and exploited for military purposes. They include bacteria, viruses, and rickettsia. They may enter the body in a number of ways, including through

the skin, ingestion, inhalation, or intravenous, or intramuscular injection. Toxins are poisonous compounds produced by living organisms. They are usually proteins that act upon specific receptors in the body and can either be lethal or highly incapacitating. Toxins are produced by a variety of organisms, including microbes, snakes, insects, spiders, sea creatures, and plants.[27]

The lethality of many of these agents is extraordinary, even when compared to chemical agents. For instance, 10 grams of anthrax spores could kill as many people as a ton of the nerve agent Sarin. With ideal conditions (a clear, calm night) a single aircraft (or UAV) using an aerosol generator to dispense a 100 kg anthrax payload (99 percent of this weight being the suspension material that allows the anthrax to be dispensed in this manner) could adequately cover a 300 km^2 area (about the size of Washington, D.C.) and inflict between 1,000,000 and 3,000,000 deaths (assuming a population of 3,000 to 10,000 people per km^2).[28] According to a 1970 report by the World Health Organization, "Inhalation of one microscopic (anthrax) spore will result in death within 48 hours. Distributed appropriately, one gram would be enough to kill more than one-third of the population of the United States."[29]

Aerosol delivery is the most effective method of disseminating biological agents. To achieve the greatest effectiveness, agents must be delivered in small aerosol particles to ensure the particles will reach the lungs. As with chemicals, aerosol devices like commercial crop sprayers are an exceptionally effective means of delivery. BW can also be delivered using conventional munitions, similar to those used for chemical weapons as discussed above.[30]

Production

Obtaining small quantities of biological agents is relatively easy. Anthrax spores exist wherever there are large numbers of sheep. Ricin can be extracted from castor beans, and Botulinum Type A, the most lethal toxin known, can be produced from bacterial strains that are readily isolated in nature.[31] Additionally, other agents, particularly some toxins, are widely used in medical research on neuromuscular diseases. Almost any agent can be legally acquired from organizations such as the American Type Culture Collection (ATCC) of Rockville, Maryland. This is an example of a legitimate business that routinely sells agents to the worldwide medical community.[32]

BW agents can be produced in either liquid or dry powdered form. Liquid agents are the cheapest and safest to produce but require special handling during transport and storage to minimize biological decay (however, this does not apply to toxins). Dried powder agents offer increased stability and improved dissemination efficiency but create greater safety hazards during production.[33]

No special facilities are required for the production of BW agents, since their production involves dual-use equipment and technologies such as those associated with legitimate endeavors. For instance, pharmaceutical plants and "baby milk" factories have some of the same equipment. From afar, these plants are indistinguishable from BW production plants. This makes them very difficult to locate and take effective interdiction efforts against.

Furthermore, developing defenses against BW requires agents upon which to experiment, so even if a country maintains a purely defensive BW program, it will, by definition, have the tools to create an offensive BW program. Also, there is no equipment unique to BW agent production, although the Australia Group has defined parameters of equipment that would be of particular utility for BW production purposes.[34]

Finally, advances in biotechnology have eliminated the need for a stockpile of BW agents. Proliferating nations need only a starter culture of agent, they can then wait until they need to use a biological weapon to produce the quantities required. This is in contrast to chemical weapons programs that require a continuing supply of sizable quantities of precursor chemicals and raw materials. Table 3 gives examples of some common BW agents and their associated lethality.

Table 3

Examples of Biological Warfare Agents

Disease	*Causative Agent*	*Incubation*	*Fatalities (%)*
Anthrax	Bacillus Anthracis	1–5 days	80
Plague	Yersinia Pestis	1–3 days	90
Tularemia	Francisella Tularensis	1–10 days	5–20
Cholera	Vibrio Cholerae	2–5 days	25–50
Venezuelan Equine Encephalitis	VEE Virus	2–5 days	<1
Q Fever	Coxiella Burnetti	12–21 days	<1
Botulism	Clostridium Botulinum Toxin	3 days	30
Staphylococcal Enterotoxemia (food poisoning)	Staphylococcus Enterotoxin Type B	1–6 days	<1
Multiple Organ Toxicity	Trichothecene Mycotoxin	Dose Dependent	

Source: *The Chemical and Biological Warfare Threat* (Washington, D.C.: Government Printing Office, April 1995), 28.

Nuclear Weapons

The weapon that most commonly comes to mind when weapons of mass destruction are mentioned is nuclear weapons. The specter of their use (or

nonuse) arguably contained the world's superpowers from engaging in direct conflicts during the cold war. To many people this means that the possession of nuclear weapons brings security for their owners and their allies. It can also be argued that they provide a means for a country to establish itself on the world geopolitical scene as a major player.

History

The first nuclear weapon used in war, code-named "Little Boy," was dropped on the Japanese city of Hiroshima on 6 August 1945. This weapon contained uranium 235 and was detonated using the gun-assembly technique. The bomb was 10 feet long, weighed 8,900 pounds, and created a blast of about 10 to 15 kilotons. Detonating at an altitude of 1,900 feet, it caused a firestorm in the center of the city that burned for days and killed approximately 69,000 of Hiroshima's 350,000 inhabitants. Twenty-two thousand more died soon after from the effects of the blast and another 30,000 died in the weeks and months that followed due to the effects of radiation.[35]

Three days later, the city of Nagasaki was the target for "Fat Man." This weapon used plutonium and the implosion technique to cause its devastating effects. Both it and Little Boy were fission weapons, producing energy by splitting the nuclei of unstable heavy atoms, such as uranium or plutonium. Part of the reaction is converted into energy, and if this happens quickly enough, a nuclear explosion is the result. Fat Man was detonated at 1,650 feet and had a yield of approximately 22 kilotons; some 70,000 people died from its effects.[36]

Research and development continued and physicists began experimenting with the concept of fusion, the combination of light atoms such as radioactive hydrogen isotopes. The results of these experiments was the hydrogen bomb, using a fission device as the trigger, with power hundreds of times greater than the fission type dropped on Hiroshima.[37]

Nuclear Weapons

The nuclear weapons constructed so far have used the isotopes uranium 235 or plutonium 239 as the fissile material. To trigger a fission reaction, it is necessary to put together a mass of these materials large enough to ensure that the high-energy neutron particles inside do not escape from the surface of the mass, but strike other heavy atoms within the material, causing them to release more neutrons and setting up a chain reaction. The smallest amount of material which will do this is called the critical mass. This amount depends on the purity and density of the material used and the physical characteristics of the bomb. Additionally, if it is surrounded by a reflective metal, like natural uranium, more neutrons are bounced back into the material, reducing the critical mass and thus the amount of material required to obtain the same explosive yield.[38]

The immediate effects of a nuclear explosion are blast, heat, and radiation. The extent to which each one comes into play depends on the size and type of

weapon and the way it is employed (ground burst, air burst, water burst, etc.). In a standard case, roughly half the energy would be released as blast, a third as heat, and the remainder as radiation, both immediately at the initial detonation and over the long term in the form of fallout.[39]

For example, a 100 kiloton weapon detonated in the air (at an altitude of less than 5,000 feet) would produce the following effects: at one to eight seconds after detonation, a fireball will appear with a temperature of about 1,000 degrees Celsius. This will sear the flesh of people in the open and dry roast or asphyxiate those in deep shelters within the blast area. Additionally, it is estimated that it will cause retinal burns to those who glance at the flash within a distance of about 10 miles from ground zero. This will be followed by the blast which, by 37 seconds after detonation, carries half the weapon's total energy. Finally, as the explosion takes on the familiar "mushroom" shape, winds suck back into the cloud, adding to the destructive effects.[40]

The last effects come in the form of radiation. Various weapons and conditions produce different combinations of radiation (neutrons, x rays, gamma rays, alpha and beta particles). The amount of absorbed radiation is measured in rads. While there is some controversy as to the "safe" amount of radiation a human body can be exposed to (and we are routinely exposed to very small amounts through natural exposure and for medical reasons), there really is no safe level of radiation exposure, and no threshold dose is so low that the risk of illness is zero.[41] In the above example, the explosion would produce the highest doses of radiation (thousands of rads) within one kilometer of ground zero. At two kilometers, the amount decreases significantly (hundreds of rads) and will continue to decrease with the distance from ground zero. However, lethal levels will extend well out from ground zero based on the prevailing winds and atmospheric conditions. The long-term effects will be felt for quite some time. Breathing even minute radioactive fallout will cause additional adverse physical effects. For instance, for cancer alone, the International Commission for Radiological Protection gives the following figures—leukemia, 20; lung, 20; bone, 5; thyroid, 5; breast, 25; and others, 50—for fatal cancers per 10,000 people induced by a dose of 100 rads.[42]

Production

The process of making nuclear weapons is highly complex and difficult. Despite the assertion that the information required to build a device is available in the public domain, considerable physics, engineering, and explosives expertise is required actually to produce a nuclear weapon. Additionally, proper high technology facilities and instrumentation must be used to achieve the required precision that such an effort demands.[43]

The fabrication of nuclear devices is made difficult by a number of other factors as well. For example, obtaining the necessary radiological material to produce a device capable of producing a nuclear explosion is a vital and relatively difficult task. This material is commonly referred to as weapon

grade special nuclear material, and although weapons can be produced with lower grade material, it usually means uranium enriched to over 90 percent of the isotope uranium 235 or plutonium with greater than 90 percent plutonium 239.[44]

Great amounts of technical skill and specialized equipment must be used in order to construct an efficient weapon. However, if maximum yield is not a key factor (as it may not be for a first time nuclear nation), lower yield, dirty weapons (weapons that are not as efficient and spread more fissionable material rather than use it optimally in the nuclear explosion) are a possible option and require less technical expertise. The gun barrel design is one such approach.

One final option for someone aspiring to obtain nuclear weapons capability would be to purchase or steal the whole weapon. This, obviously, is the most expedient way to obtain them. However, even with the increased risk that they may be available from the former Soviet Union, the worldwide proliferation community works exceptionally hard to ensure that this type of action does not occur.

Given these facts, what would be the size of a basic weapon? Unclassified sources show that simple gun barrel designs are effective for low yield weapons. This design entails one piece of uranium shaped into a cylinder to fit into a short cannon and fired through rings surrounded by tungsten and steel. On firing at extremely high muzzle velocity, the uranium passes through the rings making the mass instantaneously greater than the critical mass and setting off a chain reaction. This system is similar to ones used in tactical nuclear artillery warheads, and while it produces a low yield (unclassified yield is between 10 and 15 kilotons), it is fairly small (roughly two feet long) and weighs less than 250 kilograms.[45]

As suggested above, reports that any graduate student in physics could construct a bomb are simply not true. However, any nation with the scientific knowledge to run a nuclear reactor for electrical power generation could be expected to have the necessary skills to build a bomb. Furthermore, enriched uranium and reprocessed plutonium are both by-products of normal civilian nuclear programs. This means that countries without the necessary technical expertise, but with the money and the will, could possibly obtain the necessary materials surreptitiously.[46] Additionally, reported leakage of significant amounts of weapon-grade material from the former Soviet Union could provide a great advantage to potential nuclear "wanna-bes."[47] Sandra Meadows in a study by the Office of Technology Assessment (OTA) states that "the possibility of black-market sales of weapon-usable material may represent one of the greatest proliferation dangers now being faced."[48] Combine this with the "brain drain" (the selling of nuclear knowledge by skilled physicists from around the world), this creates a situation in which a country without the indigenous capability to build nuclear weapons might be able to obtain the necessary materials and expertise to construct them.

Conclusion

Weapons of mass destruction present a unique problem for worldwide security. Regardless of the form they take, chemical, biological, or nuclear, they have the capability to wreak havoc when employed by those who have the will to use them. As the preceding information shows, relatively small amounts of any of them can be extremely destructive. Even one or two kilograms of biological agents can be highly lethal. Chemical agents, even though they require a greater amount, are also extremely lethal. Nuclear weapons technology development has made very small warheads possible. Even though they are difficult to manufacture or obtain, they still present a significant proliferation threat. Given this fact, and the capabilities of UAVs presented in chapter 2, it appears that the two could be married to form a complete weapon. The next chapter examines this possibility.

Notes

1. *The Weapons Proliferation Threat* (Washington, D.C.: Nonproliferation Center, March 1995), 1.
2. Ibid., 1.
3. Randall J. Larsen and Robert P. Kadlec, *Bio War: A Threat to America's Current Deployable Forces* (Arlington, Va.: Aerospace Education Foundation and the Air Force National Defense Fellows, April 1995), 3.
4. *The Weapons Proliferation Threat*, 2.
5. *The Chemical and Biological Warfare Threat* (Washington, D.C.: Government Printing Office, April 1995), 1.
6. Ibid.
7. Ibid.
8. Ibid.
9. Ibid.
10. Ibid., 2.
11. Ibid.
12. Ibid.
13. Steve Fetter, "Ballistic Missiles and Weapons of Mass Destruction. What Is the Threat? What Should Be Done?" *International Security*, Summer 1991, 16.
14. Ibid., 17–18.
15. Ibid., 19.
16. *The Chemical and Biological Warfare Threat*, 5.
17. Ibid., 6–7. "The Australia Group is an informal organization of participating nations who are committed to ensuring that exports of materials and equipment do not contribute to the spread of chemical or biological weapons. The group meets biannually to discuss export controls, share chemical and biological weapons (CBW) proliferation information and to expand membership by encouraging all countries to adopt CBW proliferation controls. As with any nonproliferation regime, the Australia Group have impeded, but completely stopped CBW proliferation. However, through continuing the efforts listed above, it will remain a force in stopping the illegal transfer of CBW related material and equipment."
18. Larsen and Kadlec, 2.
19. *Biological Weapons Proliferation* (Washington, D.C.: Defense Nuclear Agency and the US Army Medical Research Institute of Infectious Diseases, April 1994), 1.
20. *The Chemical and Biological Warfare Threat*, 25.

21. Ibid., vi.
22. Larsen and Kadlec, 4.
23. Ibid., 5–8.
24. *The Weapons Proliferation Threat,* 8–14.
25. *Biological Weapons Proliferation,* 11.
26. Larsen and Kadlec, 11–12.
27. *The Chemical and Biological Warfare Threat,* 26.
28. Larsen and Kadlec, 12.
29. *Health Aspects of Chemical and Biological Weapons* (Washington, D.C.: World Health Organization, 1970), 1.
30. Larsen and Kadlec, 12.
31. *Biological Weapons Proliferation,* 15.
32. Larsen and Kadlec, 14.
33. Ibid.
34. *The Chemical and Biological Warfare Threat,* 26–30.
35. James C. Warf, *All Things Nuclear* (Los Angeles: Southern California Association of Scientists, 1989), 19–20.
36. Ibid., 20.
37. Christopher Campbell, *Nuclear Weapons Fact Book* (Novato, Calif.: Presidio Press, 1984), 10.
38. Ibid.
39. Ibid.
40. Ibid., 12–18.
41. Warf, 54.
42. Campbell, 15.
43. Albert E. Snell and Edward J. Keusenkothen, "Mass Destruction Weapons Enter Arsenal of Terrorists," *National Defense,* January 1995, 21.
44. Ibid.
45. Warf, 109.
46. Steve Weissman and Herbert Krosney, *The Islamic Bomb* (New York: Time Books, 1981), 24–25.
47. Sandra I. Meadows, "Religious, Ethnic, Nationalistic Revelries Force Redefinition of US Defense Policy," *National Defense,* January 1995, 19.
48. Ibid.

Chapter 4

A Proliferation Scenario

Chapters 2 and 3 outline various characteristics and capabilities of UAVs and WMD. From this information, one can readily draw the conclusion that UAVs are capable of providing a very good platform with which to deliver WMD. The following scenario provides an illustration of how this could occur.

Assume a nation (or terrorist group) decides, for whatever reason, that it needs a system to deliver some type of WMD. It is not particularly wealthy, nor does it possess a high degree of technical expertise. It also does not have established international partners from which it can reliably obtain financial or technical expertise.

The leaders of this nation or group believe that to be successful in this endeavor, they need to obtain a complete delivery system surreptitiously before announcing to the world their intentions. Consequently, they want to obtain the necessary equipment under the guise of peaceful applications. They see a convenient way to accomplish this goal by using UAVs to deliver WMD. However, they must make some preliminary decisions before they can proceed with acquiring the equipment and technology. First, they must decide what type of WMD they are interested in delivering. This will determine the type of UAV that will be required to deliver it.

As described in chapter 3, nuclear weapons would be the hardest to obtain and would require the greatest capability in a UAV delivery platform. For instance, the range and payload capability required to deliver a very low yield device would exceed the capabilities of all but the most expensive and technically advanced UAVs. Trying to obtain either one of these systems or the nuclear weapon would certainly cause protests from the international nonproliferation community. While it might be possible to obtain all the required equipment and materials clandestinely, doing so would be extremely difficult and expensive. Consequently, for the purposes of this example, nuclear weapons would probably not be a viable alternative.

Chemical and biological weapons, on the other hand, would be much easier and cheaper to obtain and could be indigenously produced under the guise of peaceful research. They also require a far less capable UAV delivery system. Chapter 3 outlines the characteristics of these weapons and demonstrates that small quantities, delivered by aerosol generation equipment, would be extremely effective. For this scenario, assume that chemical and/or biological weapons are the WMD of choice.

Once the weapon has been selected, the nation or group can determine and acquire the proper type of UAV to employ as a delivery system. It could

accomplish this in two ways. First it could approach legitimate UAV manufacturers using the rationale that it needs a UAV for a peaceful purpose, for example, as an efficient method of crop dusting to increase agricultural production. Second, it could approach UAV and aircraft home building manufacturers to obtain the parts to build its own UAV. Either way, it could tailor the system to fit its needs and resources.

In this hypothetical example, assume that the nation or group has access to anthrax spores and also has the capability to produce the chemical agent Sarin. It determines that in order to achieve its objectives, it needs to deliver at least a 50 kg payload (including liquefied biological or chemical agent and the spray equipment) sprayed on a target at least 150 km away. This system would be adequate to disseminate the agent over a battlefield, a water supply, or a small city.

An example of a complete UAV system that meets these requirements would be the Pioneer UAV. This system has a payload of 50 kg and a nominal range of 185 km, with a loiter time of nine hours. It has the necessary payload capability to carry the agent and the spraying system. It has the basic range (which could be more than doubled on a one-way mission because the return trip and extended loiter time over the target would not be required), and costs about $500,000 per vehicle (not including the payload). The other option, as outlined in chapter 2, is a home-built UAV, possessing roughly the same characteristics, which could be assembled from parts purchased from various UAV and aircraft kit manufacturers. This UAV would include a basic autonomous navigation and control system consisting of an autopilot and GPS receiver. This type of navigation system would make the UAV very accurate (less than 100 meters). Both of these options would provide a UAV with the necessary capability and require relatively little technical support and skill. Additionally, the vehicle is portable and does not require a sophisticated launch platform. The other required equipment is the sprayer. However, this is probably the easiest part to obtain because it is the same type of equipment used in commercial crop dusting and is widely available from sources around the world.

Naturally, the more money and technical expertise a nation or group possesses, the more capable the delivery system it could obtain and thus, the greater its WMD options. The example above is at the lowest end of the technical/monetary scale. This makes its capabilities more limited, but it is probably the easiest type of program to develop and conceal.

A very important note here is that all this must be done secretly. As chapter 5 will show, international arms and export control regimes are constantly on the lookout for those wishing to develop these types of systems. Once a determination is made that UAVs were destined for a WMD delivery role, the international nonproliferation community would make every effort to stop the program.

However, it would be fairly easy to conceal such a program because both UAVs and WMD (excluding nuclear weapons) have many dual (civil and military) uses.

Chapter 5

Analysis

Curbing the proliferation of Weapons of mass destruction and their delivery vehicles is a challenging task. Many potential proliferators are convinced they need to develop WMD and their associated delivery systems to protect their national security. It is estimated that some nations will begin exploiting the full range of UAVs, including delivering WMD in the next decade.

—Report to Congress on the Proliferation of Missiles and WMD March 1995

Chapters 2 and 3 outline the characteristics and capabilities of UAVs and WMD and chapter 4 presents a scenario that demonstrated how UAVs and WMD could be combined into an effective weapon system. Weapons of mass destruction have the capability to provide an enormous lethal punch in small quantities. While most industrialized nations with the technological and economic means to do so would probably choose more advanced delivery systems, some third world, developing nations and nonstate actors (like terrorist groups) may find this combination highly appealing.

This chapter examines what is and what could be done to stop the spread of WMD and UAV technology and the nonproliferation regimes and treaties that are currently in force and concludes with the author's assessment of the situation and some recommendations.

The Nuclear Nonproliferation Treaty

Increasingly, nuclear proliferation is acknowledged to be one of the greatest threats to global and regional peace and security. The full scope safeguards of the NPT and the International Atomic Energy Agency (IAEA) provide a first line of defense against this threat.[1]

The goals of the NPT are to prevent the further spread of nuclear weapons, to foster peaceful nuclear cooperation under safeguards, and to encourage negotiations to end the nuclear arms race with a view to general and complete disarmament. The NPT claims success in these goals. NPT adherence can eliminate the potential for a dangerous and costly nuclear arms race among nonnuclear weapon states while ensuring that the benefits of the peaceful applications of nuclear technology are made available to all members. The

NPT stipulates that nuclear weapon states agree not to transfer nuclear weapons to or assist nonnuclear states in acquiring nuclear weapons. Further, nonnuclear states undertake not to receive, manufacture, or otherwise acquire nuclear weapons.[2]

The NPT is not without its shortcomings and limitations. It has been criticized for highlighting the differences between the nuclear "haves" and the "have nots," which critics claim undermines adherence to the treaty. Further, as with any multilateral arms control agreement, it has problems dealing with those states that will not participate.[3] Finally, the IAEA's inspection and enforcement powers under the treaty are limited. A recent example of this was North Korea's refusal to allow IAEA inspection of its nuclear facilities. This resulted in a major diplomatic effort by the United States to convince the North Koreans to comply with IAEA inspectors. It remains to be seen how effective these efforts will be.[4]

The Chemical Weapons Convention

The CWC prohibits all development, production, acquisition, stockpiling, transfer, and use of chemical weapons. It requires destruction of all existing chemical weapons within 10 years after the treaty enters into force. The treaty will enter into force 180 days after 65 signatories deposit their instruments of ratification. As of 1995, 159 countries had signed the CWC and 19 countries had ratified it.[5] Three-quarters of the countries of chemical weapons concern have signed the convention; however, significant nonsignatories include Egypt, Iraq, Jordan, Libya, North Korea, and Syria.[6]

The CWC is a disarmament treaty, but because CW facilities are similar to many commercial chemical plants, and because many member-nations have developed commercial chemical industries, CWC implementation will be a massive and ambitious undertaking. Verification and other aspects of implementation of the CWC will be overseen by a new international agency, the Organization for the Prohibition of Chemical Weapons (OPCW). It will have a staff trained and equipped to inspect military and industrial facilities throughout the world, much like the IAEA does under the auspices of the NPT. Additionally, in order to begin verification as soon as the treaty comes into force, signatories have established a Preparatory Commission (PrepCom) to develop detailed implementing procedures, procure inspection equipment, hire and train inspectors, and lay administrative groundwork for the OPCW.[7]

Biological Weapons Convention

"The 135 parties to the Biological Weapons Convention of 1972 undertake not to develop, produce, stockpile, or acquire microbial or other biological agents or toxins, whatever their origin or method of production, of types and

in quantities that have no justification for prophylactic, protective, or other peaceful purposes."[8]

As with the CWC, this is also an ambitious undertaking. Over the two decades since entry into force of the BWC, confidence in the effectiveness of the convention has been undermined by instances of noncompliance. Developed countries are using the most advanced biotechnology for industrial civilian applications, and a number of developing nations also have extensive programs and expertise in this field. As explained in chapter 3, much of the same biotechnology equipment employed by pharmaceutical programs or hospital laboratories can be used to support a biological warfare program.[9] Another important point to remember is that even countries that are pursuing purely defensive BW programs have all the basic ingredients for an offensive program as well.

In order to help deter violation of, and enhance compliance with the BWC, while protecting legitimate biotechnology research interests, the United States and other signatories are developing a legally binding instrument to provide increased transparency of activities and facilities that could have biological weapons applications. A review of this instrument was conducted at the BWC Review Conference in late 1996.[10]

Australia Group

A complement to both the CWC and the BWC is the Australia Group. This is an informal organization of 28 participating nations,[11] chaired by Australia, which are committed to ensuring that exports of materials and equipment from their countries do not contribute to the spread of chemical or biological weapons (CBW). The group meets biannually to discuss export controls, to share chemical and biological weapons proliferation information, and to expand membership by encouraging all countries to adopt CBW proliferation controls. In 1994 the Australia Group took steps to strengthen existing harmonized controls on chemical weapon precursor chemicals by adopting a common approach for exports of mixtures that contain controlled precursors as normal ingredients in their formulas.[12]

As with any nonproliferation regime, the Australia Group has impeded but not completely stopped CBW proliferation. However, in combination with the CWC and BWC, it will remain a force in stopping the illegal transfer of CBW related material and equipment.

Missile Technology Control Regime

The principal multilateral instrument to combat missile proliferation is the MTCR. The MTCR is an agreement among partner nations[13] to control a common list of items (called the MTCR Annex) according to a set of common

export guidelines (the MTCR Guidelines), which each partner implements in accordance with its national legislation. Unlike the other nonproliferation regimes, the MTCR focuses on delivery vehicles, not WMD themselves. These include unmanned ballistic missiles, cruise missiles, and far less visibly, UAVs/RPVs and drones. The guidelines state that MTCR countries will restrict transfers of delivery systems (other than manned aircraft) capable of delivering a payload of 500 kg or more to a distance of at least 300 km, as well as their components and related technology, along with all missiles intended for delivering WMD, regardless of their capabilities.[14]

Complete systems, their subsystems, and specially designed production equipment and technology that meet the "300/500" criteria are considered Category I systems, and in determining their exportability, they are treated with a "strong presumption of denial." In this case, a strong presumption of denial means that a partner must, in its review of an export request, will presume to deny it. To overcome this presumption and ultimately grant the export license, the partner must evaluate the consequences of its actions in terms of the system being exported, to whom it is exported, and how it will be used. For example, the United States sold Trident missiles to the United Kingdom under the foreign military sales program. The strong presumption was overcome in this case due, in part, to the fact that the United Kingdom is an MTCR partner that agreed not to retransfer or sell the missiles and was using them for national defense. Additionally, the guidelines state that there is a strong presumption of denial to deny an export if an MTCR member judges that a missile, whether or not listed in the annex, is intended to deliver WMD.[15] Finally, they state that "until further notice, the transfer of Category I production facilities will not be authorized."[16]

As technology has evolved and the performance of unmanned delivery systems has increased, MTCR controls have also been strengthened. A good example of this is the addition of Item 19 under Category II of the annex. This item captures systems that have a range of 300 kilometers, regardless of their payload. While Category II items are not reviewed with a strong presumption of denial, they are reviewed carefully to determine if they should be exported in accordance with the guidelines.[17]

One final aspect that bears mention is the fact that the MTCR considers range and payload trade-off in determining the status of a particular export. For instance, a particular vehicle may have a range of 1,000 kilometers and a payload of 400 kilograms. If, aerodynamically, it is possible to increase its range by decreasing its payload or increase its payload and decrease its range, this vehicle would then fit into Category I and would be subject to a strong presumption of denial. This type of consideration also applies to UAVs used in a strike role. The range could be extended by using the loiter time and return trip for the one-way mission. This is a very important point when it comes to evaluating the exportability of UAVs because of their inherent range/payload capabilities.

The MTCR has grown to 28 member countries and has amassed a number of successes. For example, the MTCR was instrumental in convincing the

Argentinean government to stop the development and production of its Category I Condor missile program. Additionally, it was a major force in negotiations with the South African government that convinced them to stop the development of their long-range ballistic missile system.

The MTCR's power to enforce the tenets of the agreement is limited (they're even more limited than, say, the NPT). There are no inspection procedures or punitive mechanisms to punish violators. The strength of the regime comes from its ability to foster common export controls among the partners and also to bring severe international pressure on a country violating the rules set forth in the guidelines. A good example of this was a recent case in which intelligence sources showed that China had transferred some M-11 missile parts and equipment to Pakistan. Immediately, the MTCR partners demarched the Chinese government and requested that they cease these activities. Additionally, the United States placed export sanctions on the Chinese. The combination of these efforts proved successful and the transfers stopped.[18]

The key factor in the discussion thus far is that the world community is concerned with the proliferation of WMD and the systems that deliver them. This concern is exemplified by the formation of the various regimes and treaties developed to curb their proliferation. Where they are not completely successful on their own, the synergistic effects of all of them contribute significantly to stemming the flow of these dangerous items. However, export and arms control organizations (along with their enforcement mechanisms and the political pressure they can apply) can only do so much.

Steve Fetter outlines two other policy categories that can help. These categories are carrots and defense.[19] Carrots can come in a number of forms. For instance, security guarantees could be offered to a country that feels threatened. Promising to defend a country if it is attacked may alleviate its desire for WMD. The best option for offering security guarantees appears to lie in collective security agreements. However, this approach does have its limitations, and many nations may feel external guarantees are not sufficiently reliable to forestall the need to acquire WMD and their delivery systems.

Carrots can also come in the form of economic incentives and foreign aid. A good example of this is the agreement made with North Korea in 1995. This agreement included economic incentives to persuade North Korea to allow the IAEA to inspect its nuclear facilities.

Fetter's second category is defense. Even if the controls and carrots listed previously were completely effective, it would still be prudent to invest in some level of defense against WMD and its delivery systems. Identifying specific air defense systems that could protect the United States and its allies from attack by a UAV/WMD weapon system is beyond the scope of this study. However, what is important is that the threat that they pose is real and the value of developing systems to defend against them should not be overlooked.

One final aspect of this question that needs to be addressed is the threat of nonstate actors obtaining UAVs and using them for WMD delivery. Because

UAVs are relatively inexpensive, they are available to international and domestic terrorist groups and other nonstate actors to use in this manner. Events such as the 1995 Sarin attack in the Tokyo subway system indicate that such groups are capable of developing and using WMD. Furthermore, events like Mathias Rust's Cessna flight into Moscow's Red Square show that complete control of airspace, even by a superpower, is virtually impossible.

MTCR controls of unmanned aerial vehicles with short ranges and light payloads are limited to those systems that are known to be destined for use as WMD delivery vehicles. There are no controls on the export of other short-range UAVs. This is especially relevant to terrorist groups who may launch an attack from within a target country. It is also a concern for countries that have cities or other potential targets close to their borders as most countries do.

Export control organizations like the MTCR are concerned only with exports of controlled equipment and technology. They rely on assurances from the buyer and the buyer's country to protect this equipment and technology and use it for its stated end use. To address the potential threats posed by domestic terrorists, individual countries may need to consider internal controls (similar to domestic gun control laws) to prevent such groups from obtaining and using UAVs for terrorist purposes.

Assessment

Given the global concern about WMD proliferation, it is worth returning to the initial question proposed at the beginning of this study, Are UAVs capable of carrying WMD and if so, should this be a concern to nations concerned with nonproliferation? The research presented thus far indicates the answer is yes.

Chapter 2 demonstrates that UAVs are quite capable of carrying WMD. They have sufficient range/payload capability and are relatively inexpensive. Because they are designed to penetrate and loiter over a target and are more accurate than ever before, they are uniquely adaptable to delivering chemical and biological weapons. Additionally, because they are normally designed to be recoverable, they carry enough fuel for the penetration, loiter, and return phases of a mission. On a one-way strike mission, their published ranges could be dramatically extended because they do not need to make the return flight. This could also allow an increase in payload, though probably not a large one. Adding extra payload to a UAV would affect such flight dynamics as the center of gravity of the aircraft, thus preventing an easy range/payload trade-off calculation.

As outlined earlier, chemical and biological weapons are particularly well suited to delivery by UAVs. As little as one or two kilograms of biological agent dispensed with a commercial crop sprayer can cause devastating results. It would take substantially more chemical agents to have the same effects. However, in quantities of 50 to 150 kilograms (well within the

carrying capability of many low cost UAVs), chemical agents can be very deadly. The research also shows that both chemical and biological weapons are relatively easy to obtain and do not require great technical knowledge to produce, store, or use.

Nuclear weapons, on the other hand, present greater challenges for employment on UAVs. Acquiring a complete nuclear weapon or the material and technology to fabricate one is extremely difficult and expensive. Additionally, the size and weight requirements for even a small weapon (about 200 kilograms) is right on the edge of the payload capability of all but the most capable and expensive UAVs. While delivering nuclear payloads is a possibility, it is reasonable to conclude that UAVs are much more likely to be used to deliver CW or BW.

Recommendations

The evidence indicates that a marriage of WMD and UAVs is a possibility, that this would provide a low cost alternative to more sophisticated WMD delivery systems. It also appears that this would be an attractive option for an actor who wanted to employ WMD in its arsenal, but might lack the technological capability to do it in another way. If this is a concern, as it appears to be, what can be done about it?

The answer lies partly in an increase in the awareness of the facts that have been outlined earlier; emerging technology is making such systems more capable, more easily obtainable, and less expensive. The place to start is with the nonproliferation regimes. From a WMD standpoint, the CWC, BWC, NPT and so forth, are working to stem the availability, production, and use of these weapons. World sentiment generally appears to abhor the use of WMD, and considerable effort, money, and time have been invested in stopping their use. The key point here is that none of the WMD organizations listed earlier acting alone is nearly as successful as the synergistic effect they have acting together.

With respect to UAVs, the MTCR is the organization that is already in place and functioning with a mandate to attack the problem. The evolution of the MTCR's Guidelines and Annex have taken into account the technological advances of unmanned systems and, through the use of export controls, the regime has had some success in combating the spread of UAVs and their associated technology. However, the MTCR does not represent a complete solution to the problem of UAV proliferation.

Now is the time to "raise the red flag" of the potential of UAV and WMD use. The United States carries considerable weight and acts as a leader in all of the regimes. Additionally, there are new organizations on the horizon that could be used effectively to fight this potential threat. For instance, the successor to the Coordinating Committee on Export Controls which was an

arrangement among Western nations and was designed to deny military technology to Communist nations) is the Wassenaar Arrangement.[20]

In December 1995, 28 nations agreed to establish a new international regime to increase transparency and responsibility for the global market in conventional arms and dual-use goods and technology. This new regime is called the Wassenaar Arrangement (after the town outside The Hague where the first rounds of discussions took place). It is now just an international framework that still needs elaboration and refinement, but it would be the perfect forum for discussion of the UAV/WMD question. Additionally, its goals are tailored to respond to the new security threats of the post-cold-war world and will close a critical gap in the international control mechanisms, which have concentrated on preventing the proliferation of weapons of mass destruction and their delivery systems. While the Wassenaar Arrangement will not duplicate the other nonproliferation mechanisms, it will through a variety of means complement and, where necessary reinforce them. It is envisioned as the first global mechanism for controlling transfers of conventional armaments and a venue in which governments can consider collectively the implications of arms transfers on their international and regional security interests. In view of the close association between advanced technologies, including production technologies and modern battlefield weapons, sensitive dual-use commodities will receive the same measure of scrutiny as do arms themselves.

In a nutshell, it is envisioned that the Wassenaar Arrangement will provide an initial international framework to respond to the critical security threats of the post-cold-war world and to promote the overall nonproliferation and conventional arms transfer policies of the international nonproliferation community.[21] Given that it is in its formative months, it could provide the place to seal the leaks associated with the existing regimes and treaties associated with UAVs and WMD.

A key aspect of this (or any other nonproliferation) strategy is to increase the amount of intelligence that is available to tell if a potential buyer plans to use UAVs for WMD delivery. This is easier said than done. As technology has increased rapidly in the areas of UAVs and WMD, it has also made it harder to detect their application as complete weapon systems. Because UAVs are adaptable, moreover, the intent to use them for WMD delivery may not even exist when the export takes place. The need for reliable intelligence has proved to be the linchpin in nonproliferation and military operations alike. As recently as the Gulf War, where the best and most advanced intelligence gathering technology available was used, there were still considerable problems. Intelligence information, interpretation, timeliness, and distribution, despite the availability of imaging system and technology, was at the top of list of disappointments of the war. Gen H. Norman Schwarzkopf was very blunt in his assessment of the intelligence side of the war to the Senate Armed Services Committee when he said "there were so many disagreements within the intelligence community that by the time you got done reading many of the intelligence estimates you received, no matter what

happened, they would have been right. And that's not helpful to the guy in the fight."[22] It is particularly noteworthy that the vast extent of Iraq's WMD programs became known only through firsthand inspection after the war ended.

Both UAV and WMD technology have been available for some time. The marriage of the two into a weapon system is obviously not an original idea. Why then has it not been pursued more fully? It is difficult to provide a definite answer, but a number of possibilities exist. First, it may be because the technology is still evolving and therefore the capabilities provided by a marriage of UAVs and WMD is still developing. Advances in such areas as miniaturization of equipment, propulsion systems, accuracy of guidance systems, and advanced materials are all now available for UAV manufacturers. These developments will allow manufacturers to make yet more capable, lower cost systems in the future. If existing UAVs are already very capable of carrying WMD, logic would suggest that many new systems will be even better suited for delivering them.

Further, just because the use of WMD has been limited to this point, it does not mean that they will not be used more widely in the future. As the opening quote of this chapter indicates, the potential for its use clearly exists. The 1995 Tokyo subway nerve gas attack is a recent example. According to one writer, "Although this nongovernmental use of a weapon of mass destruction has shocked the world, those who make it their business to track the proliferation of WMD are surprised that it has taken so long."[23]

Additionally, as third world and developing nations become more economically secure, and their industrial bases mature, they may develop indigenous technologies applicable to WMD and their delivery systems.[24] This means that the number of actors (both state and nonstate) that have the capability to develop these weapons will increase. Whether these actors have the will and inclination to develop and use them remains to be seen.

Even if nonproliferation regimes and export controls are effective, proliferation can still occur. There are other options available that must be considered. Fetter argues that factors such as deterrence, sanctions, preventive war, and active defense are also important means of addressing this type of threat. The first three are punitive in nature and require a willingness on the part of the United States and its allies aggressively to confront state or nonstate actors which pursue UAV/WMD systems. Deterrence through threat of retaliation is often credited with preventing the use of chemical weapons in World War II and nuclear weapons since World War II. Economic sanctions and embargoes have also proved effective in changing an adversaries' actions. Finally, the Gulf War, although not intended as a preventive war, was very effective in destroying Iraq's nascent WMD capability.[25]

An active defense against known threats is vital. The key here is whether the UAV/WMD combination is a serious enough threat to require massive diversion of assets to develop an effective air defense system and doctrine. The answer to this question at this point is not clear. However, the prudent

course at this time would be to study the issue seriously and then decide if further action is justified.

In conclusion, the first step to combating the threat of the proliferation of UAV and WMD technology is to ensure that all the member-nations of current nonproliferation regimes and treaties are aware of the fact that these could be combined to form an effective WMD system. Second is to ensure that these regimes and treaties act in a synergistic way in order to increase their effectiveness. Third is to increase the intelligence gathering capability of systems that will be most effective in identifying potential weapons use of UAVs and the proliferation of WMD. Fourth, efforts should be taken to energize new nonproliferation organizations, such as the Wassenaar Arrangement, to incorporate mechanisms that will prevent the spread of UAVs and WMD for weapons purposes. Fifth, countries concerned about the proliferation of these systems should explore the carrots they could offer to actors that may be inclined to acquire them, in order to persuade them to do otherwise. Sixth, the United States and its allies must be prepared to address the possibility of engaging in deterrence through threat of retaliation, sanctions, and preventive war if required. Finally, given that there may still be a threat that these systems could be acquired and used against the United States and its allies, prudence would dictate that some level of effort be devoted to developing systems and procedures to defend against them. A synergistic approach such as this will provide the best means of addressing this problem.

Notes

1. *The Nuclear Non-Proliferation Treaty* (Washington, D.C.: Arms Control and Disarmament Agency, 1995), 1.

2. *Report to Congress, The Proliferation of Missiles and Essential Components of Nuclear, Biological, and Chemical Weapons* (Washington, D.C.: Department of State, March 1995), 17. With the accession of China and France in 1992, all the declared nuclear weapons states are now NPT parties. Additionally, as of the end of 1995, there were 162 total participants to the NPT. Those countries not participating include Algeria, Angola, Brazil, Chile, Cuba, India, Israel, Oman, Pakistan, Slovakia, and Tajikistan.

3. Steve Fetter, "Ballistic Missiles and Weapons of Mass Destruction. What Is the Threat? What Should Be Done?" *International Security*, Summer 1991, 33.

4. *Report to Congress, Threat Control Through Arms Control* (Washington, D.C.: Arms Control and Disarmament Agency, 1995), 73.

5. *Report to Congress, The Proliferation of Missiles and Essential Components of Nuclear, Biological, and Chemical Weapons*, March 1995, 11–12.

6. *Report to Congress, Threat Control Through Arms Control*, 22–23.

7. Ibid.

8. Ibid., 26.

9. *Report to Congress, The Proliferation of Missiles and Essential Components of Nuclear, Biological, and Chemical Weapons*, 13.

10. Ibid.

11. The 28 members of the AG are Argentina, Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Poland, Slovakia,

Spain, Sweden, Switzerland, the United Kingdom, and the United States. Requests to join the group are considered on a case-by-case basis.

12. According to officials of the Office of Chemical and Biological Weapons and Missile Nonproliferation, US Department of State, in an interview with the author.

13. As of the beginning of 1996, the MTCR Partners are Argentina, Australia, Austria, Belgium, Brazil, Canada, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Russia, South Africa, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

14. *Report to Congress, The Proliferation of Missiles and Essential Components of Nuclear, Biological, and Chemical Weapons*, 29.

15. *Missile Technology Control Regime Guidelines* (Washington, D.C.: Department of State, PM/CBM, 1995), 1.

16. Ibid.

17. *Missile Technology Control Regime Annex* (Washington, D.C.: Department of State, PM/CBM, 1995), 1–4.

18. Information on this incident was obtained from the author's firsthand account as an action officer in the Department of State, Office of Chemical, Biological and Missile Proliferation (PM/CBM) and was confirmed in an interview with the office director in February 1996.

19. Fetter, 31.

20. *Export Controls and Nonproliferation Policy* (Washington, D.C.: United States Congress, Office of Science and Technology Assessment, May 1995), 4.

21. Dr. Lynn E. Davis, under secretary of state for arms control and international security affairs, "Transcript of a Speech to the Carnegie Endowment for International Peace" (Washington, D.C.: Department of State, 23 January 1996), 1–4.

22. Richard P. Hallion, *Storm over Iraq: Air Power and the Gulf War* (Washington and London: Smithsonian Institution Press, 1992), 204 and 245.

23. "Sarin Savagery," *The Economist*, 25 March 1995, v334, number 7907, 88.

24. *Report to Congress, The Proliferation of Missiles and Essential Components of Nuclear, Biological, and Chemical Weapons*, 4.

25. Fetter, 36–38.

Chapter 6

Conclusion

Americans hold as a fundamental principle the importance of promoting international responsibility in arms transfers and in public accountability for these transfers. Preventing the spread of WMD and their associated delivery systems is essential.

—Dr. Lynn E. Davis

Curbing the proliferation of weapons of mass destruction and their delivery systems is a challenging task. Some potential proliferators seem to be convinced they need to develop WMD and/or associated delivery systems to protect or enhance their national security. Additionally, many nonstate actors (like terrorists groups) also see them as appealing weapons. At the same time, many of the technologies associated with WMD and their delivery systems have legitimate civilian and/or military applications unrelated to WMD. As developing nations increase their economic capabilities, and their industrial bases mature, they may develop indigenous technologies applicable to WMD and their delivery systems, thereby multiplying the number of countries that are potential WMD producers and suppliers.[1]

This study presents an overview of the capabilities of various unmanned aerial vehicles that established that they are capable of carrying WMD. In fact, for some weapons, such as biological and chemical agents, UAVs may well be the optimal system of delivery. It also examines the characteristics, production requirements, and availability of the various forms of WMD—chemical, biological, and nuclear weapons. It concludes that a marriage of WMD and UAVs is a definite possibility, especially for developing nations that may not have the economic or technical means to acquire or employ more advanced delivery systems. This conclusion is based, in part, on the fact that technology has progressed to the point that UAVs are now much more capable in terms of survivability, penetration capability, accuracy, reliability, and range/payload capability than they were a few years ago. Additionally, WMD have also matured and are now less expensive, more easily available, and smaller, which makes their match with UAVs a very real possibility. Finally, the dual-use nature of UAVs (intended to be reconnaissance/surveillance vehicles but possessing the capability for strike missions) and chemical and biological production facilities (which are used for medical purposes as well as weapons) makes detecting their development as weapons extremely difficult.

One possible answer to this problem is a multipurpose, synergistic approach. The basic priority is to bring this issue to the forefront and make all parties aware that the potential exists for the combined use of UAVs and WMD. The United States has the ability to exercise a significant leadership role in the international nonproliferation community. Consequently, its efforts should focus on reducing the incentives for states to develop such systems unilaterally, possibly using offers of security agreements, economic incentives, and/or foreign aid and assistance in order to persuade countries not to obtain these systems.

The United States should also prevent developing nations from acquiring WMD and UAVs intended for their delivery through existing multilateral arms control regimes. It should establish binding treaty commitments to strengthen international nonproliferation norms and seek to increase international enforcement mechanisms that punish violators. It should also encourage countries to control UAV and WMD materials and equipment in accordance with existing treaties and regimes and promote inclusion of controls for them into newly forming organizations, like the Wassenaar Arrangement. The United States and its allies must be prepared to address the possibility of engaging in deterrence through threat of retaliation, sanctions, and preventive war if required. Also, given that there still may be a threat that these systems could be acquired and used against the United States and its allies, prudence would dictate that some level of effort be devoted to developing systems and procedures to defend against them. Finally, the United States should continue its intelligence gathering efforts to detect unauthorized uses of UAV and WMD equipment and technology and share this information with other concerned nations.

The answer to this problem is not simple. In fact, there may not be a completely effective answer at all. However, a combination of solutions, as mentioned above, would have a synergistic effect that could be very successful in preventing the proliferation and use of UAVs as WMD delivery vehicles. In addition to promoting regional and international security, these measures would also aid in the protection of US citizens and interests around the world. The bottom line is that the United States may one day face an enemy that has obtained the capability to employ WMD on UAVs in battle. It is prudent to do everything in our power to prevent this from happening.

Notes

1. *Report to Congress, The Proliferation of Missiles and Essential Components of Nuclear, Biological, and Chemical Weapons* (Washington, D.C.: Department of State, March 1995), 4.

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Medusa's Mirror: Stepping Forward to Look Back "Future UAV Design Implications from the 21st Century Battlefield"

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MEDUSA'S MIRROR: STEPPING FORWARD TO LOOK BACK "FUTURE UAV DESIGN IMPLICATIONS FROM THE 21ST CENTURY BATTLEFIELD"

A MONOGRAPH
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ABSTRACT

Medusa's Mirror: Stepping Forward to Look Back: "Future UAV Design Implications from the 21st Century Battlefield" by Major David A. Brown, United States Army, 48 pages.

Will general purpose unmanned aerial vehicles, (UAVs), best meet the requirements of the twenty-first century battlefield? Although much of the information is speculative of future progress in this emerging field, this paper attempts to link available data to anticipated trends in both the international security environment and doctrinal directions embodied in Joint Vision 2010, as well as other Army initiatives.

The argument for future UAV design is captured in the conceptual framework of JV2010, a growing scarcity of UAV resources at the tactical level, and an increase in the proliferation of UAV technology both internationally and commercially. This leads into a discussion of the likely link to increased functional uses of UAV technology for military application. Validity for future speculation concerning UAV technology and its use is also based on , adaptability and projections of feasibility in terms of likelihood, cost, training, logistical support, and the near future availability of discussed technology.

"Mission specific functionality" in future UAV design is inevitable. International and commercial proliferation and the vast expansion of unmanned flight will ultimately result in an array of UAV usage much to large to place on any one platform. As UAVs proliferate, acceptance will go up, technological gains will be made, cost and size will go down, and functionality will almost assuredly increase. How this technology is developed today will have a direct impact on our ability to effectively leverage the promises of its possible capabilities tomorrow. A recommendation is that the U.S. shift developmental efforts soon enough to meet future needs before confronted with them.

Specific recommendations include continued funding UAV development efforts for the promises it holds. Secondly, continue to make current initiatives as modular as possible by diversifying capabilities through payload sensor flexibility. Thirdly, continue to fund UAV acquisition of initiatives such as Outrider UAV so as to give additional UAV capability to the tactical level. Finally, carefully research the possibility of distinct functional UAV designs, particularly in the areas of battlefield supply, and lethal UAV platforms for a variety of uses.

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TABLE OF CONTENTS

I. Introduction

What was that snaky-headed Gorgon-shield
That wise Minerva wore, unconquered virgin,
Wherewith she freezed her foes to congealed stone   Milton [1]

Such execution, so stern, so sudden, wrought the grisly aspect of terrible Medusa,
When wandering through the woods she turned to stone their savage tenants,
Like rage in marble   Armstrong [2]

For now we see through a glass, darkly   I Corinthians 13:12 [3]

In ancient Greek myth, the tale is told of Perseus who slew the Gorgon Medusa. Her appearance with a writhing mass of serpents upon her head was so terrifying that anyone who gazed upon her face was instantly paralyzed and turned to stone. In order for Perseus to kill her, he could not look at her directly. Instead, he looked at a dim reflection of her image on a highly polished shield, and walking backwards towards her, cut off her head.[4]

With headlines in defense trade journals over the last year reading, "unmanned aerial vehicles poised to become an indispensable US military asset,"[5] "UAVs vie for the sky in a billion dollar market,"[6] and "real-time surveillance sans pilot danger provides cost-effective monitoring and electronic warfare,"[7] it is abundantly clear that Unmanned Aerial Vehicles, (UAVs), are finally coming of age. Although these assets are currently not in the inventory in large quantities, we may not be planning for the best use of these assets as they become more prevalent.

Even as the Greek hero Perseus had his own hairy issue of hissing serpents, waiting for his own misstep of uncertainty, which would have resulted in stony paralysis, we

must also not allow a misstep in development of future UAV technology. Now is the time to achieve the proper mix and design of what will certainly become a major combat multiplier on future battlefields. A misstep in assessing the tangled choices of future UAV design could greatly hinder this technology's ability to meet our needs on the battlefields of the twenty-first century.

Perseus solved the problem by looking back at the problem indirectly, although the reflection was difficult to perceive. We have UAVs on the battlefield - the question is - what are they designed to do? We cannot adequately answer that question solely from today's perspective. We must attempt to "step forward" by examining the trends we are most likely to encounter on the battlefield of 2010 or beyond. We must then use those educated assumptions and speculations to look backwards, at the Medusa, through a dim mirror, helping us design today the UAVs we believe to best suited for tomorrow's use.

This paper intends to explore the differences between a general purpose and a functional design approach, and will attempt to answer the question of which of these approaches will best serve the needs of the services on the twenty-first century battlefield. Currently, UAVs are seen in the Army as generic intelligence gathering devices which can be tailored to the mission at hand. Fielding a general purpose UAV retains a certain amount of flexibility in the way that we have initially integrated the UAV concept. Another possible alternative is to build functionally specific UAV designs, each for a different purpose.

After an examination of the emerging future security environment, and a brief overview of historical and current U.S. UAV initiatives, major areas of comparison will center around the following areas: 1) stated doctrinal endstates as embodied in *Joint Vision 2010, (JV2010)*, and other service specific initiatives such as Army 2010, Force XXI, and Army After Next, (AAN); 2) scarcity of current UAV assets, 3) proliferation of UAV technology; 4) examination of a possible expansion of "mission specific" UAV military tasks; and 5) the comparable amount of adaptability between a general versus a functional future UAV design approach.

Before going further it is necessary to define the term UAV as used in this monograph. As will be later expounded on, the possible roles for UAVs are continuing to expand rapidly. For the purposes of this monograph, the term UAV, (unless otherwise specified), refers to a "powered aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload."[8]

II. Defining the Emerging Security Environment

Changing threat environments, new emerging capabilities, shrinking resources, and many other variables both known and unknown are central to this issue. In addition to the Quadrennial Defense Review, (QDR), released earlier this year by the Department of Defense, Congress is releasing their own findings concerning implications for military programs in the National Defense Panel (NDP) report to be released in December 1997.

Military and civilian planners and strategists are attempting to design a future integrated military force structure that is capable of conducting a broad range of activities stretching across the possible spectrum of the employment of military forces. This spectrum ranges from large scale, high tech combat operations against a peer competitor,[9] through security operations to deter regional powers, to serving as a protection force for humanitarian assistance efforts being conducted by the UN, local governments, or non-governmental organizations, (NGOs). The first step forward is a speculative examination or forecast of the international security environment. What are the conditions such a force will contend against and amongst? What threats will a future U.S. military force possibly face? Given that prophecy is always a tenuous prospect at best, those who attempt to part the mists of time can probably at best describe trends which might reflect the path of several possible futures.

Dr. Steven Metz is the Stimson Professor of Military Studies at the U.S. Army War College, analyst at the Strategic Studies Institute, and author of more than fifty articles on world politics and national security affairs. In wrestling with possible future security trends, Dr. Metz makes the argument that the larger security environment is in a state of transition that could eventually settle into one of several different alternative future security environments. These alternative futures range from traditional state based warfare, to one framed by states dealing primarily with internal collapse and violence. Other possibilities include a tiered environment largely along the have and have not lines, or continued conflict from primarily ideological or economic conflicts. It suffices here to

point out that Dr. Metz makes a compelling case that one of the greatest implications of this thought process is that it is possible that these environments differ significantly enough that they would argue for radically different U.S. military structures or designs.[10]

In addition to possibly radically different conflict constructs that might lead to a yet unknown post Cold War security environment, other emerging trends present themselves as part of the near future matrix of the next ten to fifteen years. These trends include:

- increased levels of information processing which impacts decision cycles
- an increase in the sheer volume of information available to individuals or groups
- Russia's and China's movement toward free market economies
- direction and growth of the European Union
- direction and expansion of a continued NATO
- continued regional conflicts in Bosnia, Korea, South West Asia, and the Middle East
- vast population growth in many under developed countries and regions
- continued technological advancement in communications and weaponry
- continued growth of international organized crime
- expanding proliferation of Weapons of Mass Destruction, (WMD), particularly by non-state actors
- increases in terrorism especially in ability to use and probability in using WMD.

This list is not inclusive and has been drawn from numerous sources. Its importance lies in seeing the breadth of the spectrum and backdrop against what a future military force must be able to contend with.

As we find ourselves gazing into this dark glass and pondering future environments, the next question that rises out of the mist is - what roles will the military be used for in one or more of the above scenarios? This is particularly hard to refine, as it is generally difficult in a democratic pluralistic society to agree on operational or strategic ends. Our elected officials are rotated on a frequent basis (in most cases) making it difficult to maintain any long term continuity. In addition, in our western mind-set, and instant

gratification society, we tend to want solutions to complex problems yesterday, or at least by tomorrow. This is seen in our voracious appetite for quick solutions: microwaves, email, faxes, drive throughs, sit-com solutions, sound bites, headlines, fast food, and exit strategies. Sometimes this leads to advocacy of unsound simple "solutions" to complex problems. Furthermore, the very diverse nature of American society makes it extremely difficult to define common ideas of what properly constitutes national interests both here and abroad.

Dr. Metz, although speaking about holistic strategies commonly found in ideologically based security systems, makes a statement that is useful for describing the problems with constructing any overall national strategy for the American government. He states, "for a variety of reasons, some dealing with the distribution of power within the government and some dealing with an attitude toward the use of force that sees it as an aberration rather than an integral part of strategy, crafting and sustaining a coherent, holistic strategy is somewhat difficult for Americans."[11] He goes on to state that to more fully integrate the use of military force into an overall strategy "would probably require fundamental reform of the strategy-making mechanisms used in the United States and fundamental reform of the policymaking system."[12]

The last National Security Strategy, (NSS), of "Engagement and Enlargement" as well as the current one of "A National Security Strategy for a New Century" both operate on the premise that the enlargement of the body of democratic nations will ultimately serve U.S. national interests given the fact that democratically elected governments make war

less frequently on other democracies, have fewer human rights violations and generally help promote regional stability.[13] Since U.S. interests are truly global in scope, the more stable regions that exist in the world, the greater mutual profit may be gained in a free market global economic environment. The National Military Strategy, (NMS), is built on supporting the NSS. The last NMS touted the two objectives of promoting stability and thwarting aggression, and assigned the military an overall strategy that promoted peacetime engagement, deterred conflict when possible, and applied decisive military force as a final option.[14] In addition, it reflected a core requirement of maintaining sufficient force to "fight and win two major regional conflicts nearly simultaneously."[15]

The question here is whether or not the force size, composition, and capabilities of a future force, (including advanced technologies such as UAVs), will be built on the basis of meeting national strategy or on non-strategy related issues such as service desires, a need to maintain national defense industry infrastructure or budgetary concerns. Shortly before the QDR was released, Secretary of Defense, William Cohen, was reported to be considering three possible future shapes of U.S. military forces based on a strategy assessment. The draft strategy document used by the QDR stated, "the demand for smaller scale contingency operations is expected to remain high over the next 10-15 years."[16] The strategy called for the need to increase spending on new military technological hardware in order to continue to improve existing military capabilities for a continuing high demand for intervention from military forces.[17] However, less than two

weeks later, leaks from the soon to be released QDR stated, "we still have dollars driving the work instead of strategy as [agencies] rush to complete their reports."[18]

The issue between strategy and resourcing is a real one with no easy answers, but of vital concern for all emerging technologies. An excerpt from a Congressional Budget Office memorandum clearly illustrates.

> DOD is facing a serious dilemma in the next decade. It wants to maintain a large number of ready and well-equipped forces so it can fight two wars similar in size to Operation Desert Storm nearly simultaneously without relying heavily on allies or civilian support. However, the funds to pay for and equip the forces that the Army would like to keep are becoming increasingly hard to come by. [19]

However, the need is to design a force that will cover the entire gambit of possible situations ranging from large scale, high tech combat operations against a peer competitor, to augmenting humanitarian assistance efforts being conducted by NGOs. It is no longer a question of a major Force on Force or some lesser Operation Other Than War - the future force must operate across the entire spectrum of possible military application. The United States' people and government demand that any future force be one which can do anything and literally everything.

Still, although the threat environment and the proposed purposes of a future force stand in close attendance, the remaining practical question of what the force must be able to do demands an answer. This is a particularly important question since it is primarily determined by what we purchase today in the way of hardware and research. Much of the debate surrounding this aspect of the future force design revolves around the question of whether or not we are in what is termed a Revolution in Military Affairs, (RMA),

which is changing or evolving the very nature of warfare and its conduct. Many recent writers have argued that we are in fact in a RMA that revolves around information processing and availability, along with added range and lethality to precision delivered munitions. While some have argued that this is nothing more than the evolution of military capability, others have indicated that the nature of what the U.S. military is doing is more revolutionary in nature and will change the conduct of war.

Particularly germane to these two emerging concepts of information processing linked to extended range precision munitions are the emergence of technologies that specifically turn these conceptions into realistic capabilities. In the "how to get there from here" category, UAV technologies touch directly on both of these areas and are the brightest stars in the dark sky of tomorrow's possibilities.

Recent experiments at the National Training Center, (NTC), to incorporate such emerging capabilities using UAVs have met with limited success. The buzz phrase coming from NTC describing part of this capability is that by using emerging technologies, (particularly UAVs), now, as never before, commanders and soldiers have the ability to know exactly where they are, where other friendly units are, and exactly where the enemy is and what he is doing.[20] It is claimed that this knowledge gives a large fundamental advantage over an adversary who does not have such technology.[21] This argument is at the forefront of *JV2010* with its four sub-elements of dominate maneuver, precision strike, full dimensional protection, and focused logistics, undergirded in all areas by a "leveraging" of information technologies. The major trends that we see in technology

for enhanced warfighting capabilities are increased weapons ranges, increased lethality, digital processing and miniaturization of components. UAV technology is the prime example of these trends for future warfare.

All of that being said, there is a caveat. UAVs, along with long range precision missiles, information technologies, or *any* technological enhancement, whether a new plane or submarine, is not by itself, a master key unlocking the solution to victory in future war. "Focusing primarily on technology also entails great risks. The never ending search for elusive silver bullet weaponry ignores the fact that once any military technology is known to exist and its characteristics are understood, it is possible to devise countermeasures that will reduce or completely negate its effectiveness."[22] There are even dangers of being susceptible to our own technology.[23] In addition to a lack of historical perspective that countermeasures closely follow technological advancement, over reliance on technology may convince decision makers to move away from sufficient conventional forces necessary to project strategic landpower in a global environment where U.S. interests are broad and far ranging. There are other useful questions that inquire about technology as a military means. Will our opponent continue to be a high technology competitor, and if not, will a high technology approach work across the spectrum of military operations? If not, then what implication does it have, if any, to the design of military forces and in particular here, for the design of military technology in the years ahead?

Be that as it may, western democracies, particularly the United States, will likely continue to pursue military superiority from a decidedly technological bent, for a variety of reasons. For one, we have the monetary resources to do so, and technology tends to be one of our nation's perceived international advantages. In addition, our nation's history tells of a lengthy romance with technological means, even to the extent that some writers have referred to America having an "abiding love affair with the machine,"[24] and an "attachment of much of their national and personal identity to technology."[25]

As an exceptional example then, UAVs present an emerging technology that will link our likely means of technological military engagement to the most likely trends of a emerging future international security environment. The possibility of this technology's capabilities, although covered more adequately later in the monograph, have the potential to make great contributions to the NSS and NMS. Specifically, of the trends mentioned earlier, UAVs have unique abilities to enhance information processing and information sharing by providing exceptional non-satellite communication retransmission capability linking commanders and units from the strategic to the tactical level. Extended ranges built into UAVs today may also give strategic planners an increased range of options in monitoring regional conflicts without deployability problems. In addition, UAVs may help provide our continued technological edge in communications and weaponry, and offer additional strategic surveillance options over a variety of uses ranging from international organized crime, to terrorism, to proliferation of WMD.

The central key here is to understand that how this technology is designed today will have a direct impact on our ability to effectively leverage the promises of its possible capabilities on future battlefields. The next step is to look specifically at the historical design, development and acquisition of this type of technology in the United States.

III. Overview of UAV Historical Background & Current US Programs

A few years ago although there were several ongoing UAV/RPV initiatives, actual working UAVs which solved tactical problems while overcoming technical limitations were few and far between. In fact, U.S. DOD historical acquisition efforts have been fraught with problems and generally disappointing.[26] "Since 1979, of eight UAV programs, three have been terminated (Aquila, Hunter, Medium Range), three remain in development (Outrider, Global Hawk, DarkStar), and one is now transitioning to low rate production (Predator). Only one of the eight, Pioneer, has been fielded as an operational system."[27] The General Accounting Office (GAO), estimates that in this same time period, DOD has spent more than two billion dollars for development and procurement of these eight programs.[28]

In the early years of these programs, there was little unity of effort as each service managed their own programs. This included the programs for Aquila, Pioneer, and the Medium Range UAV. As a result, Congress consolidated funding and DOD formed a UAV Joint Project Office in 1988, which now falls under the Office of the Secretary of Defense's, Defense Airborne Reconnaissance Office (DARO).[29] This seems to have

streamlined research, development, design, and overall consideration of UAV mission needs within DOD, and helps prevent unnecessary duplication by each service.[30]

Aquila was the first major U.S. UAV program. It was run by the Army and although initial estimates of cost were $123 million, the program cost over $1 billion, plus, (if the program had continued), an anticipated future addition of over a billion dollars for procurement of 376 airframes. The design mission included a small frame (portable by four soldiers), that sent beyond line-of-sight battlefield imagery back to ground commanders. Ultimately the small size of the airframe was unable to accommodate the desired avionics and other payload related items. In addition there were difficulties in meeting the many desired mission requirements. These requirements were only met on seven of 105 operational testing flights before the Army abandoned the program in 1987 due to "cost, schedule, and technical difficulties."[31]

Akin to Aquila was the Navy's small propeller driven Pioneer that was to be used for naval gunfire spotting and Marine Corps use. This was a joint venture with an Israeli firm, and eight vehicles were purchased in 1986. Similarly, unanticipated problems arose, in this case particularly regarding shipboard recovery and electromagnetic interference which led to numerous crashes. The Navy spent an additional $50 million to upgrade Pioneer to minimum design criteria which were considered essential for useful capability. Pioneer never met design requirements but was used with great success in Desert Storm, Somalia and Bosnia. It is currently scheduled to be phased out upon procurement of the Outrider UAV system.[32]

The third historical service effort was a joint Navy/Air Force program called the Medium Range UAV. This UAV was built as a jet designed to precede manned aircraft on a strike mission or return to the target location after the mission to collect Battle Damage Assessment, (BDA). It was supposed to be capable of a 350 nautical mile range into enemy territory and of relaying video imagery back to waiting control cells. The Navy built the airframe and the Air Force built the sensor payloads. Besides airframe crashes, the payload prototype was too large to fit into the space allotted on the frame by the Navy. The program was scrapped in 1993 due to technical difficulties and cost over runs.[33]

The first UAV to come under the Joint Project Office's auspices was the Short Range UAV later named Hunter. Begun in 1988, it also eventually doubled in cost estimates from initial assessments to an anticipated $2 billion dollars for 52 systems which would have included over 400 vehicles and associated equipment. Hunter was designed for Army Division's and Corps' (and Naval Task Force's), use as a reconnaissance, intelligence, surveillance, and target acquisition platform. Because of certain limitations, the system was forced to rely on a second Hunter in the air as a data relay platform. The dependability of this data transfer became one problem along with general system reliability. In addition, the huge support system for this vehicle led to a judgment of Hunter's unsupportability in a field environment, as well as a determination that it exceeded limited air-lift space requirements. Regardless, because of the need for some UAV capability in the force, seven Hunter systems were purchased in 1993. New

problems were found in these delivered systems' software, data transfer link, and engines. Several crashes caused the system to be grounded and the program was eventually terminated from further production in 1996.[34]

Currently there are four U.S. UAV programs being pursued by DOD and DARO generally designed around a range related concept. These systems include Outrider (short range), Predator (medium range), Global Hawk and DarkStar (both long range, high altitude - now known as High Altitude Endurance or HAE UAVs).

Outrider's program began in 1996 to meet the continuing UAV capability need at the tactical level since the termination of Hunter. Outrider was designed to be fielded down to Army Brigades (or Battalions), Marine Regiments and Naval Task Forces for primarily reconnaissance and surveillance tasks out to 200 km. Based on the success of its testing, DOD is prepared to spend over three quarters of a billion dollars by the year 2003 for development and procurement of 60 Outrider systems which will include 240 airframes and associated equipment.[35]

In order to cut through some of the lengthy acquisition process, some UAV development has been accomplished under "advanced concept technology demonstrations"(ACTDs). The Predator UAV was initially purchased under this process but has been successful enough to merit low production contracts estimated at over half a million dollars for thirteen systems which include 80 airframes. Predator will support theater and JTF levels out to 500 km with a dwell time of over twenty hours. The primary purpose of this system is also to provide reconnaissance, surveillance and target

acquisition capabilities. A much larger system than those already discussed, Predator will provide more of an adverse weather capability and include satellite relay data links. Two lost Predators over Bosnia demonstrated problems in engine reliability and vulnerabilities to hostile fire.[36]

Global Hawk is also an ACTD and a HAE UAV. It was designed to maintain altitudes of 65,000 feet with a radius of over 3,000 nautical miles (read - 6,000 miles round trip), and a dwell time (over a target area) of 24 hours at that 3,000 mile range. It is designed to remain aloft for over 40 hours. Since it has no special protection from enemy radar systems it will be used primarily in low to medium risk environments.[37] The DarkStar HAE program (also an ACTD) was created to augment Global Hawk's abilities with stealth technology that would allow operation in higher risk environments. Projected to fly at 45,000 feet or higher, DarkStar is capable of a 500 nautical mile radius with a dwell time of eight hours. These two systems are designed to utilize the same ground component for launch, recovery, command, control and communications. Several test flights of DarkStar occurred in 1996 and 1997 resulting in the crash of one system.[38]

The historical antecedents of U.S. UAV design, development, and acquisition provide a base argument for a continuing trend towards more functional, (i.e. mission task specific), UAV designs in five areas: 1) functional design's closer support of the Army's desired doctrinal related endstates, 2) current scarcity of UAV resources and its impact on tactical UAV availability, 3) international and commercial UAV proliferation's impact on a trend towards a functional design approach, 4) likely areas for expansion of military

"mission specific" UAV applications, and 5) functional design approach's greater adaptability to the needs of tomorrow's battlefields.

IV. Future UAV Design - Functional vs General Purpose (Criteria)

A. Doctrinal Directions and Related End States

1. National Security Strategy

As stated earlier our National Security Strategy is built on the premise that the enlargement of democratic nations tied to us with free market mutual trade concerns will generally help to support regional and by extension world stability. With the latest NSS, our national interests are more clearly delineated, along with areas of vital interest, or those we as a nation are prepared to direct military force to protect or maintain as an instrument of power of last resort. The major threats to our interests are broadly categorized as regional or State-centered threats, transnational threats, (such as terrorism, drug trade, organized crime and environmental damage), and threats from weapons of mass destruction.[39] In the event that military force is opted for as a strategic solution, the NSS points out that a military response encompasses a "full range" of operations up to and including major theater warfare and "accordingly, U.S. forces will remain multi-mission capable."[40] In describing a military role in our national strategy, the NSS goes on to point out that we must maintain the capability to "rapidly defeat initial enemy advances short of enemy objectives in tow theaters, in close succession," in an environment that may well be characterized by asymmetric means such as "WMD, information operations or terrorism."[41] Finally, in directing future endstates, the NSS

maintains that we must prepare now for an uncertain future by development of various capabilities in modernizing U.S. military forces.[42]

2. <u>National Military Strategy</u>

Derived from this is the National Military Strategy which closely mirrors the directives inherent in the current NSS, including the nature of future threats such as the combination of asymmetric challenges and transnational dangers, and the necessity of maintaining a credible force to deal with these threats.[43] As the NMS addresses preparation for such future conflict it specifically highlights the need for robust technological modernization to "leverage emerging technologies," specifically the "development and acquisition of new systems and equipment [that] will improve our ability to conduct decisive operations and achieve full spectrum dominance."[44] Later in the document it speaks to specific areas of capabilities and specific roles such technological advancement should be ready to support including Special Ops, Forcible Entry, Force Protection, Countering WMD, Focused Logistics, and Information Operations.[45]

3. <u>Joint Vision 2010</u>

In attempting to more clearly define the direction that current preparation efforts should work towards, the NMS emphasizes a joint vision document put out by the Joint Chiefs of Staff, (JCS), called *Joint Vision 2010,* and describes it as a "conceptual template for joint operations and warfighting in the future."[46] This document along with its subcomponent Army Vision 2010 provide what can be referred to as stated doctrinal

endstates. These are desired endstates in scope and capabilities that the services, (in this case the Army), are striving to make into reality by early in the twenty-first century. In essence, capability experiments and structural redesign considerations like Advanced Warfighting Experiments, and specifically Force XXI and the Army After Next project derive their target endstates from the template broadly provided by *JV2010*. Army Vision 2010 states that it "provides the directional azimuth for developing the doctrine for land force operations in support of *JV2010*."[47]

Secretary of Defense William Cohen's report on the recently released Quadrennial Defense Review (QDR), stated that the transformation of the force is an ongoing process and that *JV2010* provides a conceptual direction for long-range vision and plans. He goes on to state that "by undertaking efforts ranging from studies and wargames to advanced concept technology demonstrations (ACTDs), and experiments, the Armed Forces are developing and testing concepts and capabilities that will ensure their ability to transform for the future."[48] He further goes on to specifically highlight a central role in modernization to command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems.[49]

In particular to a discussion of future UAV design are the four areas of emphasis expounded upon in *JV2010* in its overall goal of being able to "leverage technological opportunities to achieve new levels of effectiveness in joint warfighting"[50] and thereby ultimately achieve what it terms "full spectrum dominance. These four areas under the umbrella of Information Superiority are Precision Engagement, Dominate Maneuver, Full

Dimensional Protection, and Focused Logistics."[51] These concepts paint a particular future mission picture. According to the Institute for National Strategic Studies' most current strategic assessment, in broad outline there will be a greater need for forces that can accomplish a very wide range of missions, particularly all of the following: [52]

- provide detailed monitoring of the battlespace in near real time
- provide precise targeting information to strike systems
- strike targets promptly with high precision
- attack while standing off from the bulk of enemy firepower
- operate in dispersed units while maintaining mission coordination
- monitor and enforce cease fire agreements between hostile parties
- monitor and enforce economic embargo or exclusion zones
- conduct effective counterterrorist operations

UAV technology is specifically designed to augment and enhance our capability to support exactly such operations as these, as well as two of the five specific "Strategic Enablers" listed by the NMS; robust all-source intelligence, and global command and control.[53] The question remains as to whether generic or general purpose UAVs will more adequately support the range of these operations and needed capabilities on tomorrow's battlefield more than functional task oriented UAVs could. As alluded to earlier, one of the issues involved concerns the building of new technologies towards these stated strategies and doctrinal directives, or suboptimizing all possibilities by revolving new technology designs primarily around budgetary "realities."

It may be that general purpose platform UAVs are inherently flexible to accomplish a wider variety of UAV missions, or it might be argued that building such generic platforms

is primarily driven by fiscal considerations as opposed to strategic and doctrinally desired endstates. Consider that by expanding the design platforms of UAVs, such as with additions of lethal UAV designs, the ability to support precision engagement and truly offer the force full dimensional protection would be greatly enhanced. In like manner, if UAVs were functionally designed, for say, logistical battlefield supply, this might greatly enhance our doctrinal stated objective of focused logistics by leveraging the emerging UAV technology of today for the battlefield needs of the next century.

Even though a close examination of desired doctrinal endstates may support future functional type UAV, historic evidence demonstrates that the development and acquisition trend has been and continues to be a general purpose UAV design approach. General purpose platform machines are inherently more flexible, but as a result of being able to accomplish a wider range of missions, fewer of such systems may be purchased on the basis of enhanced cost effectiveness. The resulting problem is that there are simply not enough systems to adequately meet future, (or even current), demand, and users habitually argue over their payload packages and mission allocations. This next segment will discuss the resulting central effect - suboptimization, and end with a discussion of the impact of UAV scarcity on tactical availability.

B. <u>Scarcity of UAV Resources & Its Impact on Tactical Availability</u>

There is a current scarcity of UAV resources. UAVs today are needed to perform a wide variety of uses and also needed by a wide variety of users and as a result there are simply not enough systems to go around. Secondly, as in any situation with scarce but

valuable resources, there is heated debate as to who should control the asset and what the asset should be doing. Although someone eventually brokers the argument through a mission needs assessment that supports the commander's intent for the situation at hand, the question is whether or not the availability of only general purpose UAVs enhances this problem.

If the UAV does a generic task (such as produce video imagery) and its product can be utilized equally by a wide variety of users, there is likely to be a struggle over control of the asset. This will be true even if the information is made available (through for example wide dissemination of downloaded material) to a wide range of users. The argument will center over where these few available assets are being deployed. In similar manner, if the system is designed to carry a variety of sensor payloads but cannot carry them all at the same time, then an argument will ensue over which sensor packages will be employed at any given time during a given mission. The same issue will arise, (and is heatedly debated today), over which targets the platform will service during any given mission.

Through the process of prioritization, the issue will be resolved. Today, with UAVs being valuable but scarce resources there is no choice but to continue such a prioritization of assets or buy more assets. The effect however is suboptimization of the asset itself. The UAV must perform a little bit of capability over a wide range of possible tasks. Everyone gets some of their needed capability from a flexible albeit overworked system. This is not enough to satisfy needed requirements, and therefore only the highest priority needs are met overall. Arguing that prioritization is a good thing does not alter the

conclusion that some needs are not being met that could enhance our capabilities on an ever more lethal battlefield environment. Those missions that get priority are enhanced. Those missions lower on the priority list, (but still vitally important), make do with less capability. Everyone gets some capability, no one gets enough.

However, if UAV systems were specifically designed or tailored to perform particular functions, the result might be; more UAVs in the system since their use would be more specialized, sufficient capabilities for each specific mission need, less cost per UAV system. Prioritization would still be necessary but prioritization in each functionally related mission area so that each area would then have at least some of their higher priorities needs met. Also, particular UAVs asset might more easily be assigned to the appropriate agency which handles a particular function within the military structure. If for example the UAV is functionally designed to map geographic features it could be assigned to a terrain team responsible for support to that mission. If the UAV is designed to collect signal intelligence, it could be assigned duty to an Electronic Warfare, (EW) team, if designed to find and/or destroy air defense radars, to the Air Force, if to provide precision targeting locations to the targeting cell, and so on. Although this approach could result in serious questions regarding manning, structure, and supportability issues, future technological enhancements such as miniaturization could significantly lessen their seriousness.

In addition to suboptimization, current UAV scarcity also greatly impacts on tactical availability. As stated earlier, current UAV supply cannot meet current UAV demand

from a wide variety of users. This pertains equally as well to the level at which the UAV is currently (or will be) available for use. As with any scarce but valuable asset, the scarcer the system is in the inventory the higher the level of command that will control its use. This is as true with satellites, U2, and ATACMS as it is with UAVs. It may be that growing numbers of UAVs will only come about as functional mission tasks need specific UAV capability. It is possible that by designing only general purpose platforms, due to their inherent flexibility, DOD will purchase fewer systems believing that the available assets can cover a wider variety of situations. Without increased numbers of UAV systems in the inventory, (which a functional approach might yield based on the fact that specialization would limit their broad use), there will always be a problem with UAV availability at the tactical level. Scarce valuable resources tend to remain at higher levels to give the entire force the benefits of their capabilities. Due to scarcity of assets, there will never be enough general purpose UAVs to perform needed requirements, but because of the inherent hierarchical structure of the military, the dearth of needed systems and their unique capabilities will remain even more acute at the tactical level than at those organizations operating at the theater or operational level.

Scarcity of UAV assets may partly stem from a historic generic "do-everything" design approach created to meet a very wide needs assessment. Is the resulting suboptimization worth the general flexibility this approach generates? In addition, there is the issue of availability of unique capabilities both in mission areas and at the tactical level. Functional UAVs might provide the answer to these issues by optimizing a UAV's

capability for particular missions, and by providing increased availability at the tactical level of these valuable combat multipliers. The key to being able to proceed towards such a functional design approach might well be found in the growing developmental markets of UAV programs that are expanding internationally for both military and commercial use. These markets show strong indications that as more and more UAVs are researched, developed and built, the uses of this technology will increase, cost will decrease, and functionality is a likely byproduct.

C. UAV Proliferation in International Programs and Commercial Initiatives

1. Impact of International UAV Proliferation

For much of the historical development of UAV technology, the promises of unmanned vehicles remained just that. As discussed earlier, problems centered around range, payload, and dwell time. However, with the miniaturization that has fueled other new technologies, the alluring promises of unmanned vehicles has almost come within modern technology's reach, Although these assets are not currently in the U.S. military inventory in large quantities and there are only a few programs in development, there is a great amount of international UAV development going on in a race to exploit UAV technology and add the capabilities of unmanned intelligence/reconnaissance to the next battlefield. There is in fact a growing proliferation of such technology on the open market.

Currently there are over 120 current UAV and programs under development world wide for various purposes.[54] These countries include Canada, China, France, Germany,

Israel, Italy, Russia, South Africa, Sweden, the UK, the US, and several international cooperative programs. For poorer nations the cost benefit alone may be sufficient to fund these efforts. UAVs are certainly less costly than satellites (although each have different capabilities), and when weighed against human or "manned" reconnaissance and the possible loss of machine - over the possible loss of life, their advantage for some operations becomes clear. From a command perspective, there are also enormous benefits in the ability to see the ground in near real time rather than waiting hours or even critical minutes, in some cases, to see what the command wants to see. This affords real reaction or planning advantages even if incapable of immediately response. If the data is within targetable range, the advantage is obvious.

Many recent writings talk about the continued robotization of the battlefield and remotely controlled vehicles and sensors. And as stated earlier, one of the growing trends in military technological equipment is increasing miniaturization. One recent article addressing this possibility in UAV technology discussed the future feasibility of hand or pocket sized UAVs. According to the Pentagon's Advanced Research Project Agency, these tiny UAVs, (possibly as small as a dollar bill), "could scout inside buildings, collect biological-chemical samples, or attach themselves to structures and equipment to act as listening or video posts."[55]

Growing use of UAVs is likely to increase significantly as more countries and more industries compete in this growing market. As one example of the encroachment of such technology onto the modern battlefield, Jane's Defense Weekly published photographs of

two Bosnian Serb soldiers holding parts of what they claimed was a Croatian UAV shot down near the western Bosnian town of Grahovo.[56] For many countries then, UAVs certainly help even the playing field for those who don't possess the technological space capabilities of an United States.

2. Impact of Proliferation into Non-military Roles

This growing proliferation is not however, limited to the military community. A former president of the Association of Unmanned Vehicle Systems stated two years ago at an international conference that "UAVs are being used for more functions every day."[57] It has been calculated that the UAV market is set to grow to around 1 billion dollars per year by the year 2000 and the commercial sector is likely to grow well beyond that.

There is growing interest in the commercial application of UAV technology although up until now most research and development has been mostly geared to solve tactical military problems. It is thought that the work already accomplished by military developers can be extended and transitioned into the civilian marketplace.

Outside of the obvious regulatory requirements needed to be worked out with such agencies as the Federal Aviation Agency, (FAA) and the Federal Communications Commission, (FCC), there are already many civilian applications that could benefit from UAV resources and many civilian agencies that currently desire to go forward with UAV programs. These UAV platforms could take many design forms: fixed, rotary wing, glider, gyroplane; heavier or lighter than air; single or multi-engine; propeller or jet; gasoline, diesel, battery, microwave or solar powered. Capabilities could also include

wide ranges of performance from "small, hand launched, low-altitude UAVs with a range of 10 km or less to large wing-span, high-altitude, long-endurance UAVs able to traverse the globe."[58]

There are a number of potential uses of UAVs outside of the military. Possible civil government applications that have been suggested include the Department of Agriculture for spraying pesticides or fertilizers, and insect sampling; NASA for high altitude atmospheric testing or sampling (such as ozone); the Postal Service for package delivery; FEMA for assessing disaster areas, relaying communications and facilitating/controlling relief operations; the Forest Service for fire control or other surveillance needs and fire fighting; the National Weather Service for storm observation; Department of Energy for monitoring nuclear sites and reconnaissance of hazardous waste sites; Department of Transportation for traffic monitoring and highway mapping; Customs for counternarcotics surveillance; Border Patrol for patrolling borders and illegal alien surveillance; DEA & FBI for suspect or counternarcotics surveillance and special weapons team support; State and Local Law Enforcement Agencies for riot control, area surveillance and search & rescue. This is only a sample of possibilities, other agencies include Merchant Marines, Fish and Wildlife, Bureau of Land Management, State Department, the National Guard, the EPA and the Army Corps of Engineers.[59] In addition, private sector applications would yield benefits for monitoring, inspections, communications relaying or quick response in areas such as real estate, maritime shipping,

farming/ranching, surveying, media, security, archaeology, railroads, as well as lumber, film, oil and mineral industries and even delivery services.[60]

In facilitating a transition of current military development to the civilian sector the military stands to increase industry interest, civilian UAV research & development, and of course spur private commercial funding for increased UAV development that might in and of itself be adaptable to future military applications as many of these stated civilian initiatives could. This type of proliferation could result in more third party suppliers for new systems, refinement of current systems, and potentially cut development and acquisition life cycle costs for future military UAV initiatives.

Growth in the civil sector of such technological enhancements will in and of itself drive further acceptance of UAV use and add to the growing presence of UAV technology both in the civilian sector and the military community. One conclusion then is that although current UAV assets are limited and must therefore be closely prioritized, their continuing technological gains, possible cost benefit savings in money and human life, and their continuing proliferation internationally both in military and in commercial sectors may ultimately result in a vastly increased range of applications for UAV technology in the years ahead.

The ensuing question then is, as the use of UAVs expand, can general purpose or generic UAV design platforms accomplish such a wide range of possible applications either in the civilian sector, or as capability and miniaturization increases in the range of a broader arena of possible military applications either? One point is clearly illustrated;

civilian agencies will build functional and not general purpose UAVs in order to tailor their use to narrowly needed specific needs. This is turn may both directly and indirectly reduce cost in developing functional UAVs for military use. The overall impact of increased UAV proliferation both internationally and commercially appears to be the likely expansion of military applications for functional UAV technology as well.

D. Potential Functional Area Applications of Tactical UAV Usage

This growing proliferation of systems and potential technological applications opens the possibility in future UAV development of a growing need to create functional UAV platforms since UAVs are unlikely to be able to carry equipment for too many technology specific missions on one vehicle. Over time, it may become more and more difficult to design one UAV platform that can perform the probable wider range of needed technological applications. Specifically for military applications, this could entail moving away from a range/dwell time management approach, to one specifically tailored to the mission a UAV is tasked to perform. UAVs could be fitted with sensors or weapons or other payloads that match a particular mission need - Jamming UAVs, radar killing UAVs, reconnaissance UAVs, IEW UAVs, or targeting UAVs. Or UAVs may be built from the ground up to meet a specific military functional need such as a battlefield delivery platform, or an expendable lethal weapon system.

1. Wide Variety of Needs in C4ISR for UAV Usage

One possible future mission specific functional UAV application is clearly command, control, communications, computers, intelligence, surveillance, and reconnaissance

systems, (C4ISR). As U.S. military forces move closer towards embracing information warfare, the role of these functions rises in direct proportion. As stated earlier, Secretary Cohen specifically highlighted expanded emphasis to the modernization efforts of C4ISR systems. UAVs provide unique abilities to enhance these specific functions through common picture imagery, but also by linking commanders on the battlefield through enhanced communications capabilities.

While image intelligence currently provides the bulk of immediate UAV mission tasks, Electronic Surveillance Missions, (ESM), EW, communication relay, and control functions are also being accepted as viable missions for UAV technologies.[61] France and Germany, for example, have been cooperating on a joint project to produce an EW specific battlefield UAV.[62] In another example, although Global Hawk's sensors were originally geared for primarily imagery intelligence (IMINT) payloads, there was an early desire (albeit not the funding) to also "integrate other capabilities such as signals intelligence (SIGINT), sensors for passive collection of communications and electronic emissions, as well as laser designator and battlefield communications relay units."[63] It is possible that in the future, UAVs could be specifically fielded to place communications and control related functions over various parts of the battlefield.

2. Targeting (D3A) Integration

Another potential future functional UAV military application is target processing. Three factors contribute to this area as an early choice for functional UAV expansion. First of all there may not be enough systems in today's force that can provide data

specific enough to be considered useful to the targeting support structure, especially considering a growth of precision strike platforms that can utilize such capability. With only a handful of UAVs available in a regional contingency, (such as Bosnia), the ratio of actual target providers to deliver systems is increasing rapidly. This is exasperated by the limited targeting specific capabilities on current UAV systems largely due to payload limitations. Secondly, enhanced weapons ranges and proliferation of precision munitions will continue to drive up demand for systems that can provide timely target collection, monitoring, and post strike assessment. Thirdly, an increased integration of targeting processing and UAV usage clearly supports current and future doctrinal concepts.

a) Scarcity of Capability & Lack of Alternate Targetable Data Providers

Because of the lack of adequate alternative targetable data providers in the current inventory, UAVs offer a particularly appealing solution to targeting needs because they can be arrayed or designed to provide targeting specific data in ways that are useful to targeting teams. Satellites and U2 data typically give an accuracy of up to 400 m, while many delivery systems require data as close as 100 m. This is equally true of the Joint Surveillance Targeting Attack Radar System, (JSTARS) which provides indications of movement or blocks of potential targets, but is, (at least currently), unable to provide data specific enough to engage specific targets.

Once a battle begins, significant portions of intelligence gathering assets are tied directly to targeting efforts to kill the enemy. This means that during tactical engagements many UAV assets will likely be taken up by targeting processes. However, this does not

mean that there are not any other significant intelligence gathering tasks that may need to be performed by UAV assets simultaneously. Lack of available targeting assets may then become critical for servicing targets by waiting weapons delivery platforms.

In the Gulf War, General Scales writes that UAVs became the only reliable system that was capable of finding passive, static targets with the precision necessary for launch of long range delivery systems such as ATACMS.[64] Besides the consternation experienced by the Air Force in clearing a path for such a long range missile, Scales reports, "the chief short-coming of ATACMS in the Gulf was the dearth of deep 'eyes' capable of spotting a lucrative target with sufficient precision and timeliness to justify expending a missile."[65]

As recently as February of this year, the Chief of Field Artillery, lamented the need of targeting UAVs for some of the reasons highlighted above. He maintains that in the future, the ability to leverage "Predator," specifically for targeting purposes will be understandably limited, and that currently "Hunter" will not be fielded for Force XXI.[66] MG Rigby goes on to argue that the UAVs we are fielding now are primarily intelligence systems and that to optimize targeting, the fire support structure needs a dedicated targeting UAV that "furnishes timely, targeting-level accuracy for high-payoff targets."[67] From warfighting exercises he also provides evidence of increased effectiveness when a UAV platform is directly linked with a delivery platform that can respond rapidly to relayed targetable data. This could be an manned air asset or a rocket/missile system like MLRS/ATACMS. In addition, the entire process becomes especially effective when

queued to other collection assets. The specific example MG Rigby provides is the link to Q-37 Firefinder radar feeds for enemy artillery target locations. From the specific location that the radar provides, the UAV can then be directed to that near vicinity to search for and provide data on additional targets.

Lack of targetable data providers is also exasperated by limited targeting specific capabilities on current UAV systems largely due to payload limitations which can prevent having useful targeting specific sensors on UAV platforms today. On larger air frames this is not as big a problem because the larger frames can accommodate various payloads of various sizes and weights, or can carry additional payloads, (like laser designators), and secure communication modules without undue impact on the UAV's aerodynamic stability. For larger manned systems such as the U2, this results in a reconfiguration ability that can accommodate various missions. However, for smaller UAVs with limited payload capabilities, the result has historically evolved into a generic platform that revolves around digital image transfer only. This means that as a generic collection asset primarily used for general intelligence data gathering, the UAV is only dedicated to the targeting process when absolutely necessary or when not performing other missions. Functional targeting UAVs could solve these problems.

b) Growing Need to Service Advanced Delivery Platforms

A second reason that targeting process might be an early choice for functional UAV expansion is the increase in enhanced weapons ranges and proliferation of precision munitions which will drive up demand for systems that can provide timely target

collection, monitoring, and post strike assessment. With the advent of more and more precision strike capabilities and long range shooters of ranges out to 300 and 500 km, the ability to have dedicated UAV technology tied to these systems will only grow more acute. One writer in discussing targeting UAVs, states, "inexpensive unmanned aerial vehicles equipped with thermal imaging technology for night targeting liked to terminally guided missile systems [will only continue] to proliferate."[68]

This concept of having the capability to actual link useable or targetable data and real time target surveillance directly to a capable weapons delivery system is where the concept of a functional UAV targeting platform becomes most apparent. As our abilities to make this reality on the battlefield increase, so will the demand for its use. As an example from one of several Army service branches wedded to targeting issues, one writer describes increased future needs for targeting capabilities as paramount to the progress towards the "Army After Next." She writes, "several warfighting capabilities will be integral to [this] evolution. The ranges of our [indirect] weapons and target acquisition systems will need to be extended out to 500 km with automatic target acquisition, target-type recognition and battle damage assessment (BDA) capabilities. We will [also] need real-time information collection and fusion capabilities to link sensor-to -shooters."[69] Dedicated targeting UAVs could be part of this future vision for targeting capabilities.

c) UAV linkage to D3A Process and JV2010

As mentioned above, a third reason that targeting might be a likely expansion of functional UAV missions is that an increased integration of targeting processing and UAV

usage clearly supports current and future doctrinal concepts. UAVs dedicated to specific targeting functions would clearly enhance all phases of our current doctrinal targeting process - D3A, (which consists of Decide, Detect, Deliver, and Assess phases).

Tactical targeting tasks are generally comprised in four areas, those of supporting the close fight, fighting the counterfire fight, interdiction of enemy forces at deep ranges, and suppressing enemy air defense assets as a support to aviation systems. In terms of the targeting process, during the Decide phase of D3A, the collection plan is built, and in the Detect and Assess phases the decisions are made as to where collection assets will look, what they are looking for, when they will look at particular locations, and finally with what resource the looking will be done with.

With availability of dedicated UAV assets the targeting process can be enhanced in each phase. In the Decide phase, targeting UAVs would contribute to other collection assets in adding to the overall collection plan. With additional eyes over the battlefield, the ability to locate higher priority targets that have already been identified as crucial Priority Information Requirements, (PIR) will be enhanced. This in turn will enhance the accuracy and efficiency of continual reassessment in advising the command on priority of targets and target categories. The Detect phase would also be enhanced because with more "eyes" available, detection efforts could be conducted earlier with assets dedicated, (within the overall collection plan), to tracking targets prior to engagement. This in turn could speed the amount of acquisitions the targeting team could service without waiting for UAV assets to become available or re-available in the Delivery phase.

As opposed to having information that a target was at a given location some period of time ago but nothing is currently available to confirm that information due to the lack of a targeting asset, dedicated targeting specific UAVs could lessen the likelihood of having to divert a UAV from a non-targeting mission to another location where it is needed for targeting purposes. This could enhance the rate of detection to delivery and (under the right conditions) provide the means to have "continuous real time" and immediate fires deployability upon detection of those targets that met criteria formulated in the Decide phase of D3A. In addition, for the Assessment phase, much more accurate and more continuous assessments of BDA could be made that would aid in immediate re-strike considerations and decisions.

Even as targeting criteria tied to dedicated collection assets in the form of functional specific targeting UAVs would clearly enhance all phases of D3A, it could be argued that a targeting functional UAV approach also supports the doctrinal concepts of *Joint Vision 2010*. Of its four emerging operational concepts two of its major provisions are closely linked with the targeting process, "Precision Engagement," and "Full Dimensional Protection." In order to better accommodate the needs for increased precision engagement, the fire support and intelligence communities are having to directly link shooters and sensors much more than they have in the past. This process allows for more timely delivery against all targets but especially against those which may not remain in one location very long, or have the ability to inflict extreme damage to the force (such as WMDs). In addition, as one of the overarching concepts of *JV2010*, functionality also

supports information warfare. Ultimately one of the main goals of information warfare is to provide commanders at all levels with an enhanced view or awareness of the battlefield so that they can more swiftly prosecute the tactical fight. The only real way to do this is to dedicate assets to the functions that can benefit by them. The targeting process is clearly one of those functions.

It is exactly this possibility of dedicating UAV assets to particular functions (as in this case, targeting), that brings to the fore, the issue of general purpose versus functional specific UAV platforms. Currently U.S. UAVs platforms are designed as general purpose platforms that have short range, medium range and long range capabilities. This is linked to which service will control the asset. For example, the Army controls UAVs which fly out to a certain range and the Air Force controls UAVs that fly to ranges beyond that. This categorization is thought to be in line with who can impact operations at the range limits that the UAV is capable of operating at. However, longer range UAVs can still provide needed capabilities at shorter ranges and the issue of resource allocation again raises its ugly head. A better categorization would be the designed function of a UAV platform, rather than length of flight time or range capability.

Although the intelligence community, has currently made provision for the broadest use of UAV utilization by placing UAV organizations down to the DS MI Company, and tied its gathered data to an all source intelligence collection process that provides the most users with the most available data, a further refinement might be to create functional targeting UAV platforms which would enhance targeting specific processes and not tie up

UAVs needed for other missions. Results could include increased availability for targeting functions, payloads or entire vehicles built to optimize specific targeting data needs, ability to service likely increases in long range delivery systems in a more timely manner, and better alignment with future doctrinal initiatives.

3. Delivery Assets vs Data Collector UAVs

Even as military imagery and data collection has been a primary function of UAV technology, there is more and more talk of UAV use for transport purposes. Commercial post carriers and cargo companies have already expressed interest in the idea of the "unmanned cargo aircraft, which would cut crew costs for them."[70] For the expansion of military applications along this line the possibilities are endless but immediate implication can be drawn to the UAV as a battlefield logistical supplier. Examples could include: munitions packages flown to forward units, emergency resupply of all supply classes, decreased use of Main Supply Routes, (MSRs), force protection for fewer combat service support personnel, and so forth.

One of the clear implications here is that current UAV designs could not accomplish such missions, therefore if this area is explored for future UAV missions, the resulting platform would by default be designed under at least a broad functional category (in this case a delivery transportation function). Additional refinements could result in further delineation of functional designs with some UAVs flying large cargo over longer distances, while other UAVs could be developed to make shorter range or smaller package deliveries.

4. Lethal vs Non-lethal UAVs

In like manner, there has been discussion of lethal UAVs specifically designed to carry deliverable weapon systems or even expendable UAV that would destroy selected targets. There has been discussion of future requirements for a "hard kill UAV for anti-radar missions,"[71] and even some suggestions that one variant of the new Joint Strike Fighter Aircraft might be an unmanned vehicle.[72] One writer in fact maintains that it is hard to imagine that advanced programs today could not "produce tactical aircraft of similar performance and superior capability to manned vehicles."[73] Another writer states that unmanned fighter aircraft have benefits in cost, and range, could take on dangerous missions like tactical reconnaissance and suppression of enemy air defenses, and "could maneuver even more violently than manned fighters (which are limited to the pilot's tolerance of 9 g's)."[74] Similarly, if UAV design expands in this direction, a functional approach is mandated automatically in order to create the desired capability.

In looking at the possible growing expansion of "mission specific" UAV tasks, for military application, in such areas as C4ISR, targeting, delivery/transportation assets, and lethal weapons platforms, one conclusion is that there will be a continued cry for increased numbers of systems to perform an ever wider variety of UAV mission tasks on the horizon. Certainly reconnaissance, stealth strike, long-range electronic warfare, and logistical delivery platforms are all candidates for the expansion of applications in UAV technology use in areas that have traditionally been fulfilled by manned vehicles.[75] This motif of not only growing proliferation of the amount of projected use of UAVs but the

expansion of roles that can be included in their repertoire of capability leads to a possible conclusion that while general purpose platforms can do many things well, they cannot hope to accomplish the wider litany of purposes future UAVs are likely to be asked to perform. All of this argues that a functional design approach may achieve a greater degree of adaptability to the needs of tomorrow's battlefields.

E. Adaptability

1. Flexibility through Standardization (General Purpose)

In discussing future UAV design based on likely future needs, one approach is to build general purpose platforms designed to operate at various ranges that could download visual and locational data of the enemy to a wide variety of field users across the spectrum of conflict. Certainly an advantage in this type of approach is flexibility in terms of the vehicle's use. For example, an imaging platform could serve uses in reconnaissance, surveillance, or target acquisition (at high enough resolutions). As a practical result the vehicle could be made available to a wide variety of uses and users without the limitations imposed from making the platform so specialized that only certain users could benefit from its utility. Another advantage would be in supportability across units or services. Common chassis based vehicles simplify the ordering, stockpiling and general sustainability of any platform, not to mention an easier training process from documentation to instructional support for using personnel. Our current U.S. systems are designed around fairly generic functions to operate at various range depths and differing dwell times.

One of the major problems with a general purpose approach is the ever increasing need for the platform to provide one more functional capability. In other words, can a general purpose platform do everything we want it to be able to do? Can any one system do everything. This problem was specifically addressed in the most recent GAO UAV review.

One of the major conclusions of the report on UAV acquisition was that "the more you ask a UAV to do, the harder it becomes to build."[76] The finding goes on to state, that system programs like this must be protected from "requirements creep." In other words, just because new capabilities can be added to a UAV system does not mean that they should be. As highlighted earlier in the historical review of U.S. programs, UAV systems designed with an initial mission function have been at least partly undermined by additional requirements.[77] The GAO conclusion is that proposed new requirements must be judged on the overall effect on the system in terms of "cost, schedule and performance."[78]

2. Flexibility through Design (Function Specific)

If, as this paper has explored, there is increasing proliferation of UAV technology and expanding roles for its use, then general purpose UAVs, (although offering the major advantage of standardization) are the ones most likely to be continually bombarded with requests for the platform to ever increase its repertoire of capability. This seems at least in part intuitively obvious if the demand for functional capability does expand. The alternative is to build UAVs that are designed specifically to meet certain mission

requirements creating an alternative form of adaptability in terms of increased use of UAV technology but adaptable from the standpoint of functional design. It could be argued that the very reason that current systems are designed with different range depths, and generally thought to be directed at different levels of the spectrum of conflict (tactical, operational/theater, and strategic), is to support the contention that there is a need for different functions, for different missions, at different levels.

One short term solution that combines some of the advantages of both general purpose UAVs with designed functionality is to move towards general purpose airframe platforms and gain needed functional diversity through payload design. This in fact seems to be the current direction that U.S. UAV systems are moving.[79] The distinctions for UAV design could grow less distinct as new UAV technologies enter the marketplace. It may become just as easy to provide longer flights and communication/control at longer distances with the miniaturization of components. This would mean that common flight platforms could remain airborne for as long as needed over any part of the world desired in support of both tactical commanders or strategic decision makers. The key to adding mission functional distinctiveness would be in tailored payloads. In this particular regard the problem with "requirements creep" could be side-stepped as long as the new capability resided in a modular payload that fit the dimensional and weight restrictions of the airframe. Again, with increased miniaturization, this becomes increasingly possible. Already we do a limited similar process on tailoring payloads on fighter aircraft (for weapons packages) and on such aircraft as the U2. What is most gained in this approach

is mission adaptability which allows the commander to utilize the right tool for the right job at the right time. This however also requires substantial technological enhancements in several areas, without again arriving at the point of suboptimization. What is not solved by this approach is resource scarcity and resulting prioritization issues. It is also clear that functional design is absolutely necessary to pursue capabilities such as battlefield resupply, expendable weapon platform, or unmanned fighter aircraft.

A discussion of the possible utility of functional payload leads us to another important question, of whether or not UAV type technology can in fact be "purchased off the shelf" and adapted for military mission requirements. This is particularly evident if the new requirement is "available" on the open market. Another conclusion resulting from the latest GAO UAV review was that such availability should not necessarily be construed as being automatically mature in capability when combined into a military requirements package. Although the resulting cost savings of a "nondevelopmental item" is attractive, off the shelf technology "cannot be assumed to meet DOD or service requirements when subjected to the rigors of realistic operating environments or wartime operation tempos."[80] Civilian technological applications not built to military specifications often neglect both logistical and MANPRINT issues necessary to military operations. The GAO went on to say that making such technology useful to the military user can be extremely costly.

F. Additional Considerations

Related problems to the question of general versus functional UAVs needing to be addressed are concerns over UAV logistical support, organizational structure and training issues. One of the best ways to understand the nature of the these issues is to understand that when you are buying a UAV, you are buying much more than the airframe itself. The air vehicle is only the most visible portion of the system. A UAV system also includes "computer processors, software, sensor payloads, data links, data dissemination equipment, ground control stations, launch and recovery equipment, and a logistics support network."[81] Time and time again, DOD has been confronted with the need to test how all of these things interact successfully together as a complete system, and evaluate how affordable the entire system will be to operate and maintain over its entire lifecycle prior to considerations of production or procurement.[82] MG Israel, Director of DARO, is quoted as saying, "many people oversimplify UAV technology. Developing UAVs is not simply taking composite materials and slapping an engine on an airframe."[83]

Thinking of UAVs as systems contributes to a host of related topics which this paper is unable to adequately address. One of the greatest implications and historical lessons learned from the Hunter program was the need to consider the logistical support package necessary to sustain the UAV in a field environment. If the support package is too large, this greatly impacts on the ability to project the equipment where ever the system is needed (at least in a timely fashion, if at all) due to inadequate air lift capability that could be dedicated to the movement of UAVs vice other needed equipment. Structural and

organizational questions also arise as to which units have the ability to maintain, operate and sustain the system with personnel and logistical support. If the supporting structure is too large or its operation is overly technical, training issues are also raised that must be addressed.

V. <u>Recommendations and Conclusions</u>

Dr. Edward Teller, who helped to develop the atomic and hydrogen bombs, predicted in the late 1970s that man would control unmanned aerial vehicles over intercontinental distances.[84] Today that vision is coming about, as modern UAVs are coming of age. But looking through the mist of a hazy future security environment and its implications for new military technologies, will the preparation we accomplish today serve us well on tomorrow's battlefields? Two emerging technological concepts stand out as future key combat multipliers: information dominance, and extended range precision munitions. Almost as a linchpin between them, UAVs provide the means to exploit these concepts to their fullest degree.

Today, U.S. UAV design is making great headway for the short term. Our design approach is built on cost effective, general purpose platforms that offer some inherent flexibility and offer some savings in cost, training and sustainability. In addition, with an renewed emphasis on modular payload sensors, flexibility and mission application are being expanded.

It is however a short sighted approach and one that may in fact not meet the growing UAV needs of the coming century. Today, partly because of cost benefit, UAVs are

scarce but valuable resources resulting in contention over their use between military functions and services, and greatly reducing the tactical availability of these extraordinary capabilities. As a result, the demand, if not the minimum essential requirements go largely unmet.

The decision to build UAVs designed around a particular mission, or "mission specific functionality" is not really a choice at all. International and commercial proliferation and the vast expansion of unmanned flight will ultimately result in an array of UAV usage much to large to place on any one platform. Its like watching the very first car come out of development and making an assumption that all motorized vehicle needs could be served by a few common vehicle configurations. As UAVs proliferate, acceptance will go up, technological gains will be made, cost and size will go down, and functionality will almost assuredly increase. The only real choice is whether or not we will shift our developmental efforts soon enough to meet future needs before we are confronted with them. How this technology is developed today will have a direct impact on our ability to effectively leverage the promises of its possible capabilities tomorrow.

Specifically I recommend that we continue to fund UAV development efforts for the promises it holds. Secondly, we should continue to make our current initiatives as modular as possible by diversifying capabilities through payload sensor flexibility, (particularly enhancing C4ISR and targeting capabilities). Thirdly, we should continue to fund UAV acquisition of initiatives such as Outrider UAV so as to give additional UAV capability to the tactical level. Finally, we should carefully research the possibility of

distinct functional UAV designs, particularly in the areas of battlefield supply, and lethal UAV platforms for a variety of uses.

UAVs present an emerging technology that will link our likely means of technological military engagement to the most likely trends of an emerging twenty-first century battlefield. GEN Joseph Ralston, Commander of Air Combat Command, stated in Defense News, Aug 95, that "UAVs have enormous potential, but they are going to present enormous challenges to fit into our overall construct."

We must look backwards from the needs of the years ahead. And whereas we are bound to get some answers wrong, neither will we be caught in Medusa's gaze, frozen in the past without the weapons that will enhance not only our survival but our dominance in future wars. The mirror is dim, and although we do see through a glass darkly, if we peer hard enough, there are enough faint images of what we need to know to step forward in the right direction.

ENDNOTES

[1] Thomas Bulfinch, *Bulfinch's Mythology,* (New York, NY: Harper & Row, 1970), 117.

[2] Ibid.

[3] *The Holy Bible, "The First Epistle to the Corinthians,"* King James Translation, (New York, NY: Oxford University Press, 1967), 1245.

[4] Robert Graves, *The Greek Myths, Volume One,* (New York, NY: George Braziller, Inc, 1959), 239. See also Arthur Cotterell, *The Macmillan Illustrated Encyclopedia of Myths & Legends,* (New York, NY: Macmillan Publishing Co., 1989), 149, 220.

[5] Title subheading on Glen Goodman, "New Eyes in the Sky," *Armed Forces Journal International*, July 1996, 32.

[6] Title cover on *Jane's Defense Weekly,* Vol 24, No 6, 12 August 1995.

[7] Title subheading on CAR, "Europe's Unmanned Aerial Vehicles Enable Fast Action," *Signal,* Vol 51, No 1, September 1996, 31.

[8] In addition, ballistic or semiballistic vehicles and artillery projectilies are generally not considered UAVs. This definition is consistent with all of DOD's UAV Master Plan documents. The sited quotation and the following definitions are taken specificially from the Unmanned Aerial Vehicles Joint Project Office, Department of Defense, *Unmanned Aerial Vehicles 1994 Master Plan,* (Washington, D.C.: U.S. O.S.D., May. 31, 1994), F-1. Other useful definitions include the following:

Remotely Piloted Vehicle (RPV): An unmanned vehicle capable of being controlled from a distant location through a communications link. It is normally designed to be recoverable.

Nonlethal UAV: An UAV that does not carry a payload for physical damage and/or destruction of enemy targets. It carries payloads for missiona such as RSTA; target spotting; C2; meterological data collection; NBC detection; special operations support; communications relay; and electronic disruption and deception. Most of the time the term UAV is synonymous with "nonlethal UAV."

Lethal UAV: An UAV, normally autonomous and expendable, that carries a payload used to attack, damage, and/or destroy enemy targets. Lethal UAVs are more specifically addressed in the classefied Department of Defense Standoff Weapons Master Plan.

[9] *Strategic Assessment, Flash Points and Force Structure, 1997,* Washington, DC: National Defense University Press, 1997, 233. This assessement points out that the most obvious candidates for peer competitors "are China or Russia, but possibly one of the larger regional powers, such as India, could transform itself into a major military power in the next decade." This source also more clearly delineates this type of threat by providing the following caveat. "It is not necessary to specify which one of these powers could be the source of problems, because all of the major powers that the US might confront in the foreseeable future share sufficient characteristics that it is possible to describe a composite, which we refer to as a *potential theater peer.* That term captures the essence of the military challenge from such countries: they are not peers with the US, able to challenge it world-wide, but they may have sufficient power to be a peer with the US in a theater of operations near them." These are generally construed to be continental, nuclear, and space capable nations of "enormous size and resources which for practical reasons cannot be overrun or occupied."

[10] Steven Metz , "*STRATEGIC HORIZONS: The Military Implications of Alternative Futures,*" (Carlisle Barracks, PA: Strategic Studies Institute, 1997), vi - viii, 1-52.

[11] Ibid. p. 41.

[12] Ibid.

[13] For additional support for this idea - see for example Think-Tank work such as *Foreign Policy into the 21st Century: The U.S. Leadership Challenge,* (Washington, DC: The Center for Strategic & International Studies, 1996), xii, which states that "not only has history shown that industrialized democracies are among the countries least likely to go to war with one another, but they also have significant trade-related incentives for resolving lesser conflicts in a cooperative manner."

[14] *National Military Strategy of the United States of America, 1995,* (Washington, DC: US Government Printing Office, 1995), i.

[15] Ibid., ii.

[16] Colin Clark, "Major Force Structure Cuts Loom, Says Top Army Official," *Defense Week*, 14 April 1997, 1.

[17] Bradley Graham, "Cohen Weighing Three Possible Courses for Shape of Future US Military," *Washington Post*, 04 April 1997, 4.

[18] Clark.

[19] Ibid.

[20] Scott R. Gourley, "US Glimpses a 'Digitized' Future," *Jane's International Defense Review*, Vol 30, September 1997, 54.

[21] "In all operations, technological advances and the use of information will provide major qualitative advantages to war fighters at the individual crew and small unit levels." Cited from CAR., (Staffwriter-no name supplied), "Aerial Reconnaissance Boosts Battlefield Awareness Scheme," *Signal*, Vol 51, No 9, May 1997, 36.

[22] Hirsh Goodman and W. Seth Carus, *The Future Battlefield and the Arab-Israeli Conflict*, (London: Transaction Publishers, 1990), 167; quoted in Douglas Macgregor, *Breaking the Phalanx*, (Westport, CT: Praeger, 1997), 3, n. 6.

[23] See for example Charles Dunlap's article "How We Lost the High-Tech War of 2007 - A Warning From the Future," *The Weekly Standard*, 29 January 1996, 22-28.

[24] See specifically, Michael L. Smith's article, "Recourse of Empire: Landscapes of Progess in Technological America," in Merritt R. Smith, & Leo Marx, eds. *Does Technology Drive History?* (Cambridge, MA: The MIT Press, 1994), (37)-52. For a look at current American writing on possible future technologies' cultural impacts and interactions, see Kevin Kelly, *Out of Control*, (New York, NY: Addison-Wesley Publishing Co., 1994).

[25] Ibid.

[26] Director, Defense Acquisitions Issues, National Security and International Affairs Division, *Unmanned Aerial Vehicles, DOD's Acquisition Efforts*, United States General Accounting Office Report, GAO/T-NSIAD-97-138, (Washington, D.C.: U.S. General Accounting Office, 1997), 1. Testimony before Subcommittees on Military Research, Development and Procurement, Committee on National Security, House of Representatives.

[27] Ibid.

[28] Ibid.

[29] Ibid.

[30] DARO as an example did a technology study and made a list of 70 technologies considered important to extended reconnaissance. The four broad functional categories

these technologies fell in were, platforms, sensors, information processing and communications. Challenges in current reconnaissance capabilities listed as continuous broad area coverage, higher resolution data for targeting, improved sensors for BDA, improved over the horizon commo and connectivity, increased commo bandwidth, better data retrieval and distro, comprehensive source correlation, and better synchronization with users. DARO is investing in technologies ranging from propulsion, to avionics, to processing. Cited in CAR., (Staffwriter-no name supplied), "Aerial Reconnaissance Boosts Battlefield Awareness Scheme," *Signal,* Vol 51, No 9, May 1997, 36-38.

[31] GAO UAV Overview Report, GAO/T-NSIAD-97-138, 2. Aquila was meant to have autopilot, sensors to locate/identify point tgts day or night, and a laser for artillery delivered Copperhead projectiles. It was supposed to be able to support normal artillery support and survive Soviet style ADA defenses. This required a "jam-resistant, secure communications link," the use of which degraded the video which in turn degraded targeting ability. See also, *Aquila Remotely Piloted Vehicle: Its Potential Battlefield Contribution Still in Doubt,* (GAO/NSIAD-88-19, Oct. 26, 1987), and *Unmanned Vehicles: Assessment of DOD's Unmanned Aerial Vehicle Mater Plan,* (GAO/NSIAD-89-41BR, Dec. 9, 1988).

[32] Ibid, 3. See also *Unmanned Vehicles: Assessment of DOD's Unmanned Aerial Vehicle Mater Plan,* (GAO/NSIAD-89-41BR, Dec. 9, 1988).

[33] Ibid. See also *Unmanned Aerial Vehicles: Medium-Range System Components Do Not Fit,* (GAO/NSIAD-91-2, Mar. 25, 1991).

[34] Ibid, 4. See also *Unmanned Aerial Vehicles: No More Hunter Systems Should Be Bought Until Problems are Fixed,* (GAO/NSIAD-95-52, Mar. 1, 1995), and *Unmanned Aerial Vehicles: Maneuver System Schedule Includes Unnecessary Risk,* (GAO/NSIAD-95-161, Sep. 15, 1995), and *Unmanned Aerial Vehicles: Hunter System Is Not Appropriate for Navy Fleet Use,* (GAO/NSIAD-96-2, Dec. 1, 1995).

[35] Ibid.

[36] Ibid, 5. Note: Predator still requires a large support group and deployments in support of operations in Bosnia have highlighted limitations under certain weather conditions. The Air Force has assumed operational command of the remaining ACTD assets.

[37] Ibid, 5-6.

[38] Ibid.

[39] *A National Security Strategy for a New Century*, May 1997, (Washington, DC: US Government Printing Office, 1997), 5-6.

[40] Ibid., 12.

[41] Ibid.

[42] Ibid., 13.

[43] *National Military Strategy of the United States of America, Shape, Respond, Prepare Now: A Military Strategy for a New Era*, 1997, (Washington, DC: US Government Printing Office, 1997), 9-16.

[44] Ibid., 18.

[45] Ibid., 27.

[46] Ibid., 17.

[47] *Army Vision 2010,* (Washington, DC: Department of Defense, Department of the Army, 1996), 9.

[48] William S. Cohen, "Report of the Quadrennial Defense Review," *Joint Force Quarterly*, Summer 1997, 12.

[49] Ibid.

[50] *Joint Vision 2010,* (Washington, DC: Department of Defense, Chariman of the Joint Chiefs of Staff, 1996), 1.

[51] Ibid., 19-25.

[52] *Strategic Assessment, Flash Points and Force Structure, 1997,* (Washington, DC: National Defense University Press, 1997), 258.

[53] *NMS*, 1997, 28.

[54] See Chart in Steven J. Zaloga, "UAV Military Future Deemed 'Promising'," *Aviation Week & Space Technology*, 13 January 1997, 92-97. See also charts in, Charles Bickers, "Systems Worldwide," *Jane's Defense Weekly* , Vol 24, No 6, 12 August 1995, 38; and Doug Richardson, "Unmanned Aerial Vehicles Stretch Their Wings," *Armada International*, Vol 20, No 5, Oct - Nov 1996, 10-11.

[55] Stacey, Evers, "ARPA Pursues Pocket Sized Pilotless Vehicles," *Jane's Defense Weekly*, Vol 25, No 12, 20 March 1996, 3.

[56] Photograph and heading in Charles Bickers, "Tier II - Plus: Taking the UAV to New Heights," *Jane's Defense Weekly*, Vol 24, No 6, 12 August 1995, 37.

[57] Charles Bickers, "UAVs Take Off Into a Multifunction Future," *Jane's Defense Weekly*, Vol 24, No 6, 12 August 1995, 33.

[58] Unmanned Aerial Vehicles Joint Project Office, Department of Defense, *Unmanned Aerial Vehicles 1994 Master Plan,* (Washington, D.C.: U.S. O.S.D., May. 31, 1994), C-4.

[59] Ibid., C-4 - C-5.

[60] Ibid.

[61] Bickers, "UAVs .... Multifunction Future," 33.

[62] Ibid., 34.

[63] Bickers, "Tier II-Plus: Taking the UAV to New Heights," 34.

[64] Robert Scales, Jr., *Firepower in Limited War,* (Novato, CA: Presidio Press, 1995). 261.

[65] Ibid., 260.

[66] Randall Rigby, "Targeting UAVs," *Field Artillery Journal*, Jan-Feb 1997, 2.

[67] Ibid.

[68] Douglas Macgregor, *Breaking the Phalanx*, (Westport, CT: Praeger, 1997), 127.

[69] Susan Walker, "Fires 2020 - The Field Artillery Roadmap," *Field Artillery Journal*, March-April 1997, 33.

[70] Bickers, "UAVs .... Multifunction Future," 33.

[71] Ibid., 34.

[72] Ibid.

[73] Ibid.

[74] David A. Fulghum, "Defense Dilemma: Force Structure or Modernization," *Aviation Week & Space Technology*, 17 March 1997, 80.

[75] Bickers, "UAVs .... Multifunction Future," 34. For additional mission expansion roles see also, William B. Scott, "USAF Set to Fly 'Mini-Spaceplane'," *Aviation Week & Space Technology*, 4 August 1997, 20-21. This article maintains that small unmanned spacecraft could eventually perform reconnaissance and weapon delivery missions.

[76] GAO UAV Overview Report, GAO/T-NSIAD-97-138, 6. (cited in note 26 above).

[77] See earlier discussion under section III - Overview of UAV Historical Background & Current US Programs, for examples of additional requirements that contributed to technical over-reach such as the add on to initial Aquila design requirements for precision targeting capability.

[78] GAO UAV Overview Report, GAO/T-NSIAD-97-138, 6.

[79] U.S. systems are generally moving towards payload functionability if not full functionality. The director of DARO is looking for a flexible approach through pods which he believes "reduces reconfiguration time, and allows a single hardware configuration to support multiple missions." He states in the same article, "we want to consolidate platforms." Cited in CAR., (Staffwriter-no name supplied), "Aerial Reconnaissance Boosts Battlefield Awareness Scheme," *Signal,* Vol 51, No 9, May 1997, 38.

[80] GAO UAV Overview Report, GAO/T-NSIAD-97-138, 7.

[81] Ibid.

[82] Ibid.

[83] CAR., "Aerial Reconnaissance Boosts Battlefield Awareness Scheme," 38.

[84] Staffwriter-no name supplied, "Vigorous Visions." *Signal,* Vol 51, No 9, May 1997, 3.

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Strikestar 2025

A Research Paper
Presented To

Air Force *2025*

by

Col (Sel) Bruce W. Carmichael
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Maj Patrick E. Pence
Maj Richard S. Wilcox

August 1996

Disclaimer

2025 is a study designed to comply with a directive from the chief of staff of the Air Force to examine the concepts, capabilities, and technologies the United States will require to remain the dominant air and space force in the future. Presented on 17 June 1996, this report was produced in the Department of Defense school environment of academic freedom and in the interest of advancing concepts related to national defense. The views expressed in this report are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States government.

This report contains fictional representations of future situations/scenarios. Any similarities to real people or events, other than those specifically cited, are unintentional and are for purposes of illustration only.

This publication has been reviewed by security and policy review authorities, is unclassified, and is cleared for public release.

Contents

Illustrations

Tables

Preface

We examined unmanned aerial vehicles (UAV), knowing that similar research had produced naysayers and even some active hostility. However, we are genuinely concerned for future modernization efforts as budgets and manpower decrease. We came to an early conclusion that manned vehicles provide a flexibility and level of accountability far beyond that of unmanned vehicles. But considering our changing world, the use of unmanned vehicles for missions beyond reconnaissance is both technically feasible and cost-attractive. We envision the UAV proposed here to be a force multiplier for the air and space warrior—a new tool in the warrior's arsenal.

Executive Summary

The United States military of the year 2025 will need to deal with a wide variety of threats in diverse parts of the world. It will be faced with budgetary restraints that will dictate system trades favoring those military elements that offer utility over a wide spectrum of conflict and add to the ability to project power over long distances. The United States military of the year 2025 will also exist in a social and political environment that will dictate the need to minimize United States personnel losses and enemy collateral damage.

An opportunity exists to exploit planned advances in intelligence, surveillance, reconnaissance, and the development of unmanned aerial vehicles (UAV) to address future military needs. Through all-source, coordinated intelligence fusion, it will be possible to supply the war fighter with all-weather, day or night, near-perfect battlespace awareness. This information will be of precision targeting quality and takes advantage of multiple sources to create a multidimensional view of potential targets. Early in the twenty-first century, reconnaissance UAVs will mature to the extent that reliable, long-endurance, high-altitude flight will be routine, and multiple, secure command and control communications links to them will have been developed.

The obvious extension of these developments is to expand UAV use to include lethal missions. In 2025, a stealthy UAV, we refer to as "StrikeStar," will be able to loiter over an area of operations for 24 hours at a range of 3,700 miles from launch base while carrying a payload of all-weather, precision weapons capable of various effects. Holding a target area at continuous risk from attack could result in the possibility of "air occupation." Alternatively, by reducing loiter time, targets within 8,500 miles of the launch and recovery base could be struck, thus minimizing overseas basing needs.

A concept of operations for this UAV will include various operation modes using the information derived from multiple sources to strike designated targets. In developing and fielding this type of a weapon system, a major consideration will be carrying weapons aboard unmanned vehicles. However, the StrikeStar

UAV concept has the potential to add new dimensions to aerial warfare by introducing a way to economically and continuously hold the enemy at risk from precision air attack.

Chapter 1

Introduction

The 2025 study was chartered to look at twenty-first century airpower needs and postulate the types of systems and capabilities that would be useful to future war fighters. This paper targets the potential contributions of unmanned aerial vehicles (UAV) to the future war fighter. Specifically, it looks at an expansion of the UAV's role from its present reconnaissance emphasis to encompass a multimission strike role. Although open-source literature speaks of using UAVs in combat support roles, less has been written about the use of such aircraft as lethal platforms. This paper helps to address this shortcoming and should stimulate the thinking necessary to make the organizational and cultural changes that will utilize UAVs in this new role.

The paper is organized to show where we are in the field of UAVs, delineate the need for this new capability, and discuss some nontechnical considerations that must be addressed before this capability is fielded. It then looks at the technology required to bring this concept to fruition, and, finally, shows the ways a lethal UAV could be employed.

It should be understood there is a variety of forms a lethal UAV could take as well as a variety of performance capabilities it could exhibit. The concept of lethal UAVs found in the Air Force Scientific Advisory Board's *New World Vistas: Air and Space Power for the 21st Century* is but one form a lethal UAV could take. Their concept of a high-speed, highly maneuverable UAV capable of performance far greater than current manned fighter aircraft offers one future capability. This paper looks at a different UAV capability emphasizing long-loiter and cost-effectiveness. This is a concept of "air occupation"—the ability to hold an adversary continuously at risk from lethal or nonlethal effects from the air.

Chapter 2

Historical Development and Employment

Unless you plan your strategy and tactic far ahead, unless you implement them in terms of weapons of tomorrow, you will find yourself in the field of battle with weapons of yesterday.

—Alexander de Seversky

The United States Air Force will remain actively engaged in all corners of the globe and at all levels of the conflict spectrum. Yet at the same time, the military budget is decreasing, overseas bases are closing, and there is political and social pressure to keep United States and adversary casualties to a minimum in any future conflicts. The situation, as described, is unlikely to change much in the future. As the Air Force adapts to this new set of realities and meets it commitments to the nation, it will need to look at new ways and methods of doing business. One of the most promising future possibilities is the increased use of unmanned aerial vehicles (UAV) to perform tasks previously accomplished by manned aircraft. Unmanned aircraft have the potential to significantly lower acquisition costs in comparison with manned alternatives, thus enabling the fielding of a more robust force structure within constrained budgets. Unmanned aircraft can also be tasked to fly missions deemed unduly risky for humans, both in an environmental sense (i.e., extremely high-altitude or ultra long-duration flight) as well as from the combat loss standpoint. The Department of Defense (DOD) recognized the potential value of the UAV through its support of the Defense Airborne Reconnaissance Office's (DARO) advanced concept technology demonstrations (ACTDs) of a family of long-endurance reconnaissance UAVs. However, the DARO UAVs, along with other improvements in reconnaissance and communications, will lead to even greater possibilities in the use of UAVs to project precision *aerospacepower*[1] to all parts of the world and to remain engaged at any level of conflict.

The Early and Cold War Years

The use of UAVs is not a new experience for the United States armed forces or those of many other states. The German use of the V-1 in World War II showed that unmanned aircraft could be launched against targets and create a destructive effect.[2] Unfortunately, the V-1 was a "use and lose" weapon. Once launched, it was designed to destroy itself as well as the target. In the 1950s, the United States developed an unmanned intercontinental-range aircraft, the Snark. Designed to supplement Strategic Air Command's manned bombers in nuclear attacks against the Soviet Union, this unmanned aircraft also destroyed itself as it destroyed the target. In effect, these were precursors of today's cruise missile.

In the United States, the UAV has normally been associated with the reconnaissance mission and designed to be a recoverable asset for multiple flight operations. The remotely piloted vehicles (RPV) of the early 1960s were developed in response to the perceived vulnerability of the U-2 reconnaissance aircraft, which had been downed over the Soviet Union in 1960 and again over Cuba in 1962.[3] "Red Wagon" was the code name for a 1960 project by Ryan Aeronautical Company to demonstrate how its drones could be used for unmanned, remotely guided photographic reconnaissance missions.[4] As early as 1965, modified Ryan Firebee drones were used to overfly China with some losses experienced.[5]

In 1962, in conjunction with the development of the Central Intelligence Agency's manned A-12 (similar to the SR-71 Blackbird) reconnaissance aircraft, Lockheed began development of the D-21 supersonic reconnaissance drone (fig. 2-1). The D-21 (code-named "Tagboard") was designed to be launched from either the back of a two-seat A-12 (designated M-12 for this project) or from under the wing of a B-52H.[6] The drone could fly at speeds greater than Mach 3.3, at altitudes above 90,000 feet, and had a range of 3,000 miles.[7] At the end of the D-21's mission, the reconnaissance and navigation equipment as well as the exposed camera film could be parachuted away from the airframe and be recovered by a specially equipped aircraft.[8] The project was canceled in 1971 due to numerous failures and the high cost of operations.[9]

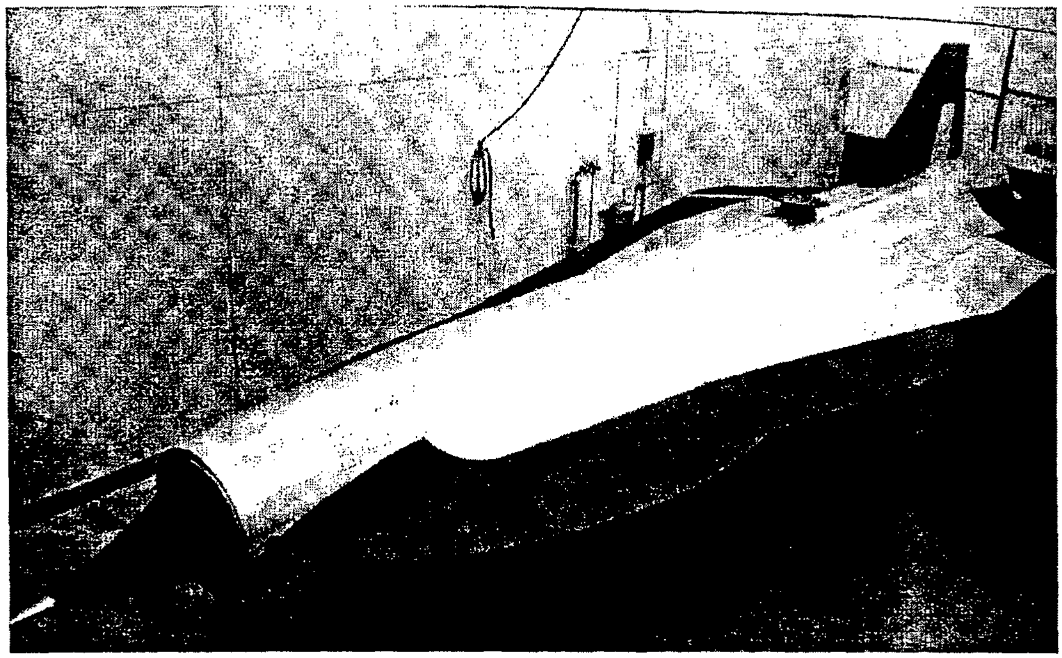

Figure 2-1. D-21 Tagboard

The best known United States UAV operations were those conducted by the United States Air Force during the Vietnam War. Ryan BQM-34 (Ryan designation: Type 147) "Lightning Bug" drones were deployed to the theater in 1964.[10] From the start of operations in 1964 until missions were terminated in 1975, 3,435 operational drone sorties were flown in Southeast Asia by the Strategic Air Command's 100th Strategic Reconnaissance Wing.[11] These air-launched UAVs flew both high (above 60,000 feet) and low (below 500 feet) altitude missions. Mission durations were as long as 7.8 hours. Types of missions flown included photo reconnaissance, leaflet dropping, signals intelligence collection, and the laying of radar-confusing chaff corridors to aid penetrating strike aircraft.[12] The average life expectancy of a drone in Southeast Asia was 7.3 missions with one aircraft, the Tomcat, flying 68 missions before being lost (fig. 2-2). Recovery rates for operational unmanned aircraft in Southeast Asia were approximately 84 percent with 2,870 of the 3,435 sorties recovered.[13]

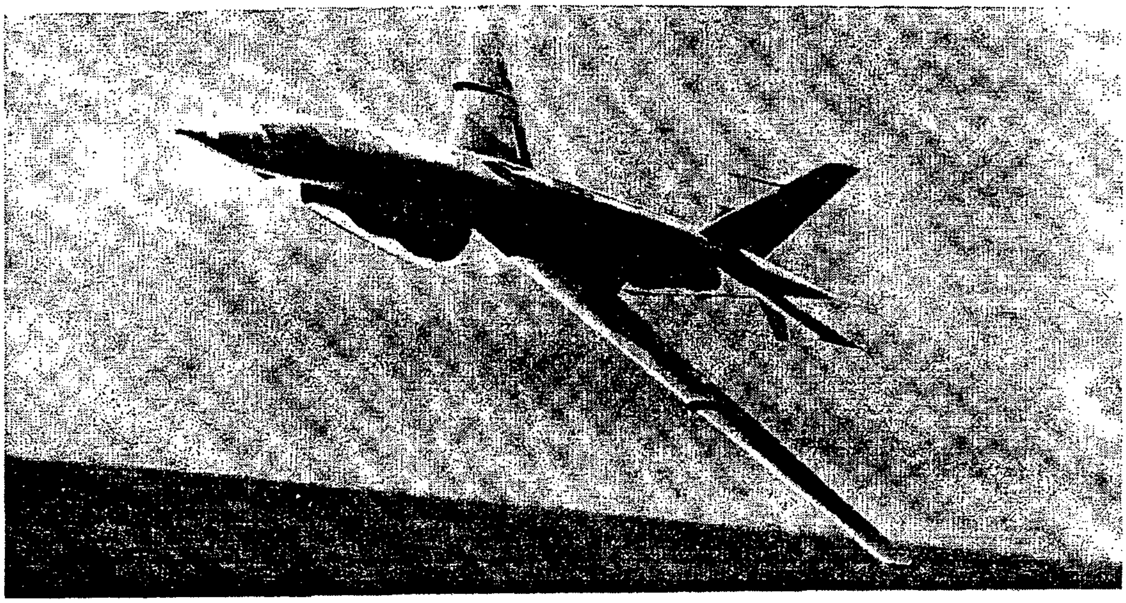

Figure 2-2. BQM-34 UAV, Tomcat

In addition to the reconnaissance role, Teledyne Ryan also experimented with lethal versions of the BQM-34 drone. In 1971 and 1972, drones were armed with Maverick missiles or electro-optically guided bombs (Stubby Hobo) in an attempt to develop an unmanned defense suppression aircraft to be flown in conjunction with manned strike aircraft (fig. 2-3). The thinking behind this project was that an unmanned aircraft ". . . doesn't give a damn for its own safety. Thus every unmanned bird is a potential Medal of Honor winner!"[14]

The Israelis effectively used UAVs in 1973 and 1982. In the 1973 Yom Kippur War, the Israelis used UAVs as decoys to draw antiaircraft fire away from attacking manned aircraft. In 1982, UAVs were used to mark the locations of air defenses and gather electronic intelligence information in Lebanon and Syria. During the war, the Israelis used UAVs to continually monitor airfield activities and use the information that was gathered to alter strike plans.[15]

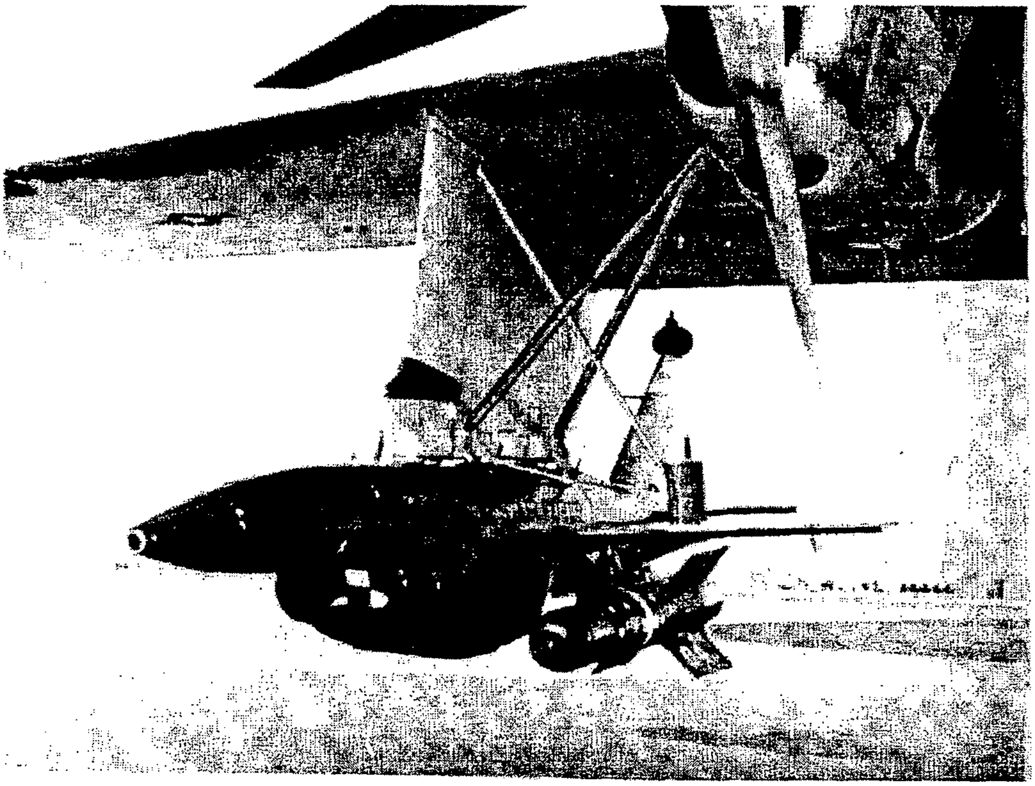

Figure 2-3. BQM-34 UAV with Stubby Hobo

The Gulf War and Its Aftermath

The United States "rediscovered" the UAV in the Gulf War. The Pioneer UAV (fig. 2-4) was purchased by the Department of the Navy to provide inexpensive, unmanned, over-the-horizon targeting, reconnaissance, and battle damage assessment (BDA).[16] The Army purchased the Pioneer for similar roles and six Pioneer systems (three Marine, two Navy, and one Army) were deployed to Southwest Asia to take part in Desert Storm. During the war, Pioneers flew 330 sorties and more than 1,000 flight hours.[17]

In the aftermath of the Gulf War, the United States began to look more closely at the use of the reconnaissance UAV and its possible use to correct some of the reconnaissance shortfalls noted after the war. Space-based and manned airborne reconnaissance platforms alone could not satisfy the war fighter's desire for continuous, on-demand, situational awareness information.[18] As a result, in addition to tactical UAVs, the United States began to develop a family of endurance UAVs that added a unique aspect to the UAV program.[19] Three different aircraft comprise the endurance UAV family.

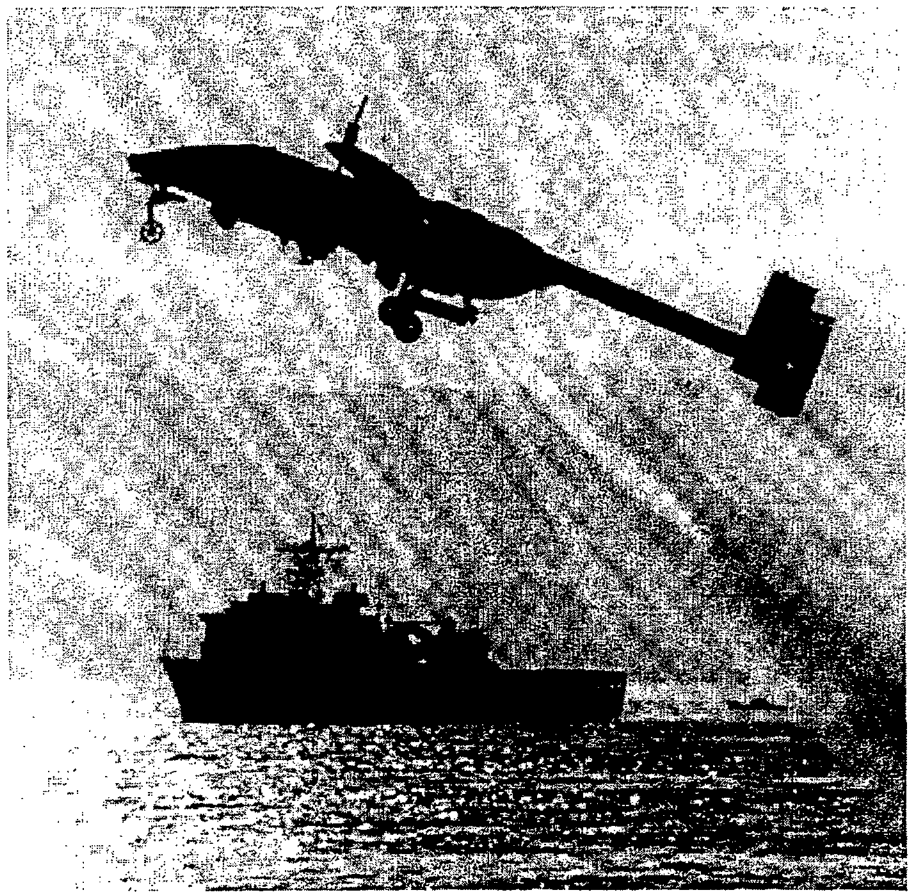

Figure 2-4. Pioneer on Sea Duty

The Predator UAV is an outgrowth of the CIA-developed Gnat 750 aircraft (fig. 2-5).[20] Also known as the Tier II, or medium altitude endurance (MAE) UAV, the Predator is manufactured by General Atomics Aeronautical Systems and costs about $3.2 million per aircraft.[21] It is designed for an endurance of greater than 40 hours, giving it the capability to loiter for 24 hours over an area 500 miles away from its launch and recovery base.[22] It is powered by a reciprocating engine giving it a cruise speed of 110 knots, loiter speed of 75 knots, ceiling of 25,000 feet, 450 pound payload, and a short takeoff and landing capability. The Predator carries an electro-optical (EO) and infrared (IR) sensor and was recently deployed with a synthetic aperture radar (SAR) in place of the EO/IR sensor. The Predator is also unique in its ability to collect full-rate video imagery and transmit that information in near real-time via satellite or line of sight (LOS) data link.[23] The Predator first deployed to Bosnia in 1994 and has since returned there with two combat-related losses (see appendix A).

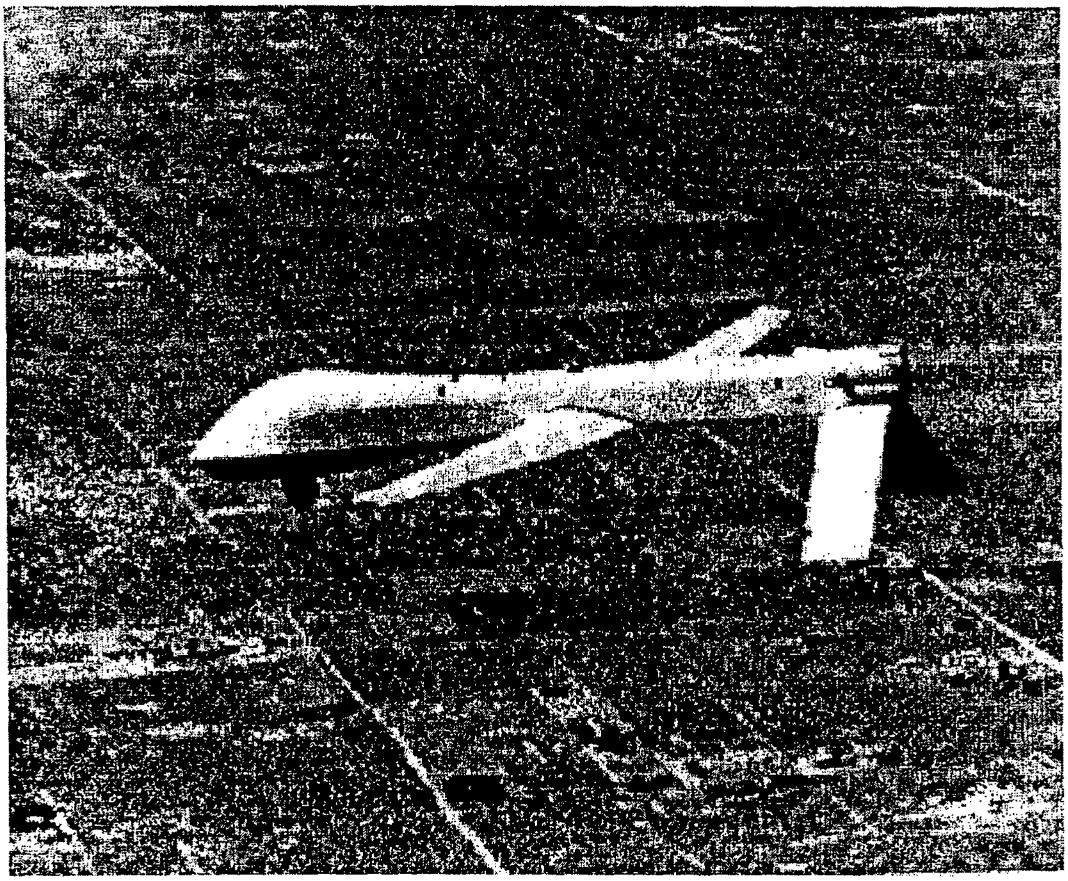

Figure 2-5. The Predator UAV

A higher performance vehicle is the Teledyne Ryan Aeronautical Conventional High Altitude Endurance (CHAE) UAV (fig. 2-6). Referred to as the Tier II+, or Global Hawk, it is designed to fulfill a post-Desert Storm requirement of performing high-resolution reconnaissance of a 40,000 square nautical mile area in 24 hours. The Global Hawk is designed to fly for more than 40 hours giving it a 24-hour loiter capability over an area 3,000 miles from its launch and recovery base. It will simultaneously carry a SAR and an EO/IR payload of 2,000 pounds and operate from conventional 5,000 feet runways. The aircraft will cruise at altitudes above 60,000 feet at approximately 340 knots.[24] Tier II+ is scheduled to fly in late 1997 and meet a price requirement of $10 million per unit.

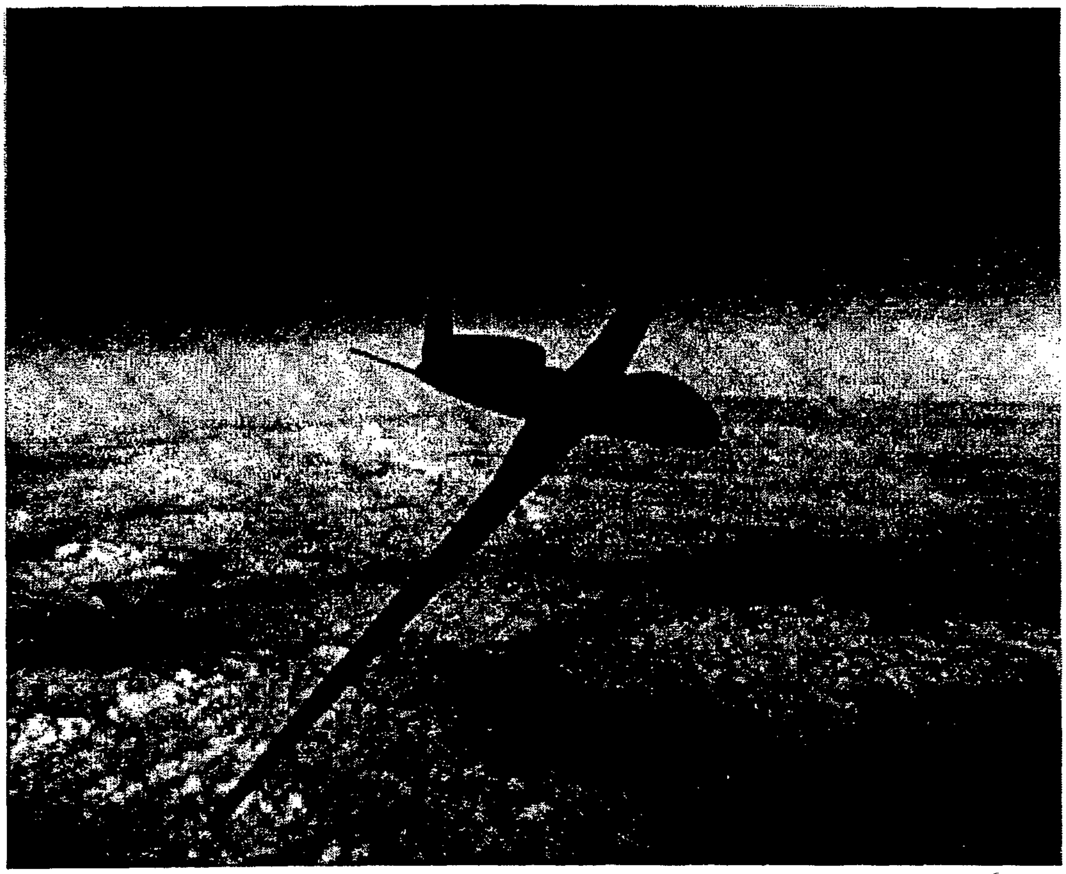

Figure 2-6. The Global Hawk UAV

The low observable high altitude endurance (LOHAE) UAV (Tier III- or DarkStar) is the final member of the DARO family of endurance UAVs (fig. 2-7). DarkStar is manufactured by Lockheed-Martin/Boeing and is designed to image well-protected, high-value targets with either SAR or EO sensors.[25] It will be capable of loitering for eight hours at altitudes above 45,000 feet and a distance of 500 miles from its launch and recovery base. DarkStar can be flown from runways shorter than 4,000 feet. DarkStar's first flight occurred in March 1996.[26] This UAV is also designed to meet a $10 million per aircraft unit fly-away price. DARO's new endurance UAVs, along with manned airborne reconnaissance aircraft, are designed to meet Joint Requirements Oversight Council (JROC) desires for the development of reconnaissance systems that are able to ". . . maintain near perfect real-time knowledge of the enemy and communicate that to all forces in near-real-time."[27] DARO's goal is "extended reconnaissance," which is "the ability to supply responsive and sustained intelligence data from anywhere within enemy territory, day or night, regardless of weather, as

the needs of the war fighter dictate."[28] The objective is to develop by the year 2010, a reconnaissance architecture that will support the goal of "extended reconnaissance."

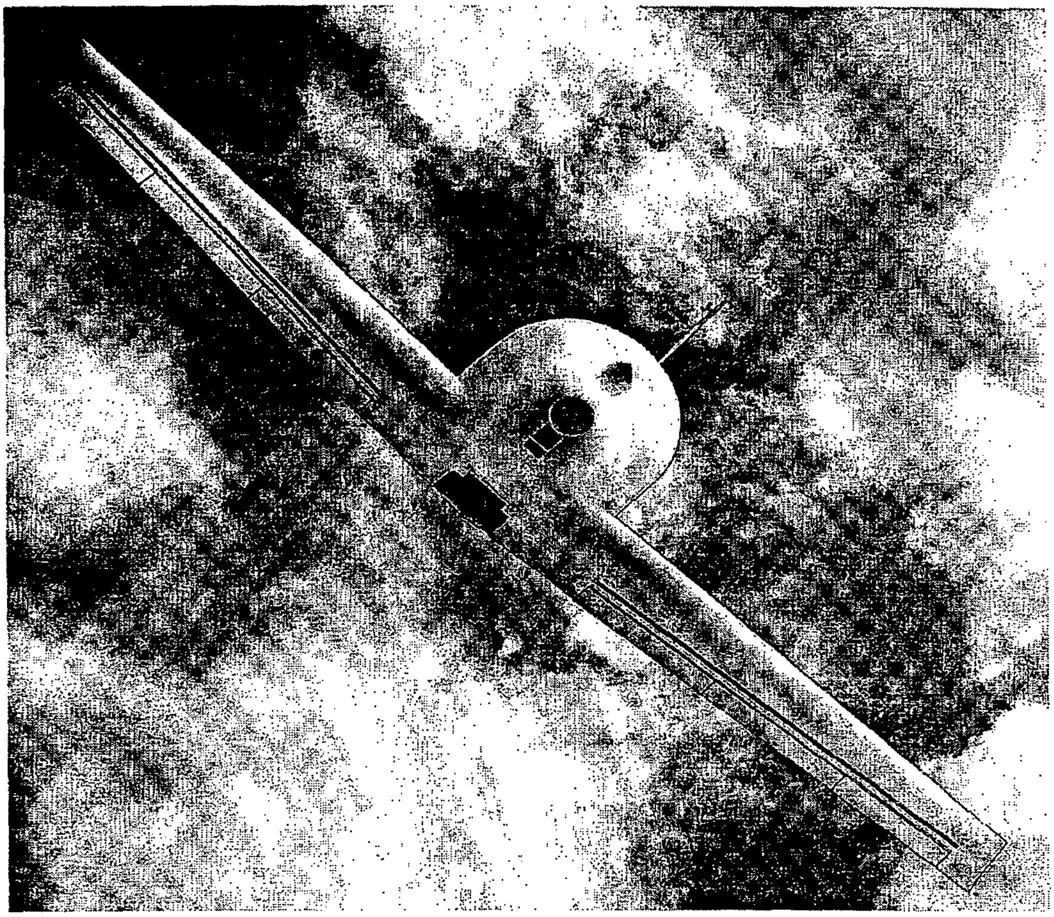

Figure 2-7. The DarkStar UAV

To do this, DARO will consolidate platforms, introduce endurance and tactical UAVs, emphasize all-weather sensors as well as multispectral optical sensors, improve information systems connectivity to the war fighter through robust line-of-sight and over-the-horizon communications systems, produce scaleable and common-use ground stations, and focus on the benefits of interdisciplinary sensor cueing.[29] In conjunction with spaceborne and other surveillance assets, this objective architecture will provide the war fighter and command elements with near-perfect battlespace awareness.

The seamless integration of airborne and spaceborne reconnaissance and surveillance assets, along with robust, on-demand communications links, coupled with the experience in long-endurance, high-altitude UAVs made possible by current DARO efforts, will lead to the next step in the development and employment of

unmanned aerial vehicles—the long-endurance, lethal, stealthy UAV. A possible name for this new aircraft could be "StrikeStar," and we will refer to it by that name throughout this paper.

StrikeStar will give the war fighter a weapon with the capability to linger for 24 hours over a battlespace 3,700 miles away, and, in a precise manner, destroy or cause other desired effects over that space at will. Bomb damage assessment will occur nearly instantaneously and restrike will occur as quickly as the decision to strike can be made. StrikeStar will allow continuous coverage of the desired battlespace with a variety of precision weapons of various effects which can result in "air occupation"—the ability of *aerospacepower* to continuously control the environment of the area into which it is projected. The next chapter explores the requirements that drive the StrikeStar UAV concept.

Notes

[1] The term "aerospacepower" is used as one would normally use the word "airpower" and reflects the inseparability of air and space assets in 2025. In 2025, there will be no air and space power, only aerospacepower.

[2] Dr Michael H. Gorn, *Prophecy Fulfilled: Toward New Horizons and Its Legacy* (Air Force History and Museums Program, 1994), 28–35.

[3] Paul F. Crickmore, *Lockheed SR-71 - The Secret Missions Exposed* (London: Osprey Aerospace, 1993), 9,16.

[4] William Wagner, *Lightning Bugs and Other Reconnaissance Drones* (Fallbrook, Calif.: Aero Publishers, Inc., 1982), 15.

[5] Ibid., 115.

[6] Jay Miller, *Lockheed's Skunk Works: The First Fifty Years* (Arlington, Tex.: Aerofax, Inc., 1993), 134–135; Ben R. Rich, *Skunk Works* (N.Y.: Little, Brown and Co., 1994), 267.

[7] Miller, 141.

[8] Crickmore, Lockheed SR-71, 38.

[9] Rich, 269.

[10] Lt Col Dana A. Longino, *Role of Unmanned Aerial Vehicles in Future Armed Conflict Scenarios* (Maxwell AFB, Ala.: Air University Press, December 1994), 3; Wagner, 52.

[11] Wagner, 52, 200.

[12] Ibid., 197.

[13] Ibid., 200, 213.

[14] Ibid., 185.

[15] Ibid., 6.

[16] *Unmanned Aerial Vehicles*, Defense Airborne Reconnaissance Office Annual Report (Washington, D.C., August 1995), 5.

[17] Longino, Role of Unmanned Aerial Vehicles, 9.

[18] *Unmanned Aerial Vehicles*, 7.

[19] Steven J. Zaloga, "Unmanned Aerial Vehicles," *Aviation Week and Space Technology*, 8 January 1996, 87.

[20] Ibid., 87.

[21] David A. Fulghum, "International Market Eyes Endurance UAVs," *Aviation Week and Space Technology*, 10 July 1995, 40–43.

[22] *Unmanned Aerial Vehicles*, 27.

[23] David A. Fulghum, "Predator to Make Debut Over War-Torn Bosnia," *Aviation Week and Space Technology*, 10 July 1995, 48.

[24] David A. Fulghum, "International Market, 43.

[25] Zaloga, Unmanned Aerial Vehicles, 90–91.

[26] "Tier III- DarkStar First Flight Video," *Lockheed-Martin Skunkworks*, 29 March 1996.

[27] *Airborne Reconnaissance Technology Program Plan - Executive Summary*, Defense Airborne Reconnaissance Office (Washington, D.C., February 1995), 2.

[28] *Unmanned Aerial Vehicles*, 1.

[29] Ibid., 4.

Chapter 3

The Need for A Strike Unmanned Aerial Vehicles

What we need to develop is a conventional deterrence force, similar to our nuclear triad, that we can project and sustain over long distances.

—Gen Ronald R. Fogleman

As 2025 approaches, the use of unmanned aerospace vehicles will be driven by sociocultural, geopolitical, and economic forces. Although it is impossible to see the future, some assumptions can be developed about the year 2025:

1. Americans will be sensitive to the loss of life and treasure in conflict.
2. The US economy will force its military to be even more cost-effective.
3. Technology will give potential enemies the ability to act and react quickly.[1]

These strategic assumptions create operational needs the US military must meet by 2025. UAVs are one cost-effective answer to those needs and have the potential for use across the spectrum of conflict. Although the need for advanced capabilities is continually emerging, this concept identifies constraints that create a demand for lethal UAVs in 2025 and a possible solution to that need. By 2025, limitations may cause gaps in US airpower and UAVs offer the ability to bridge them.

Current Forces

Currently, the triad of conventional aerospace forces consists of carrier-based aircraft, land-based strike aircraft, and CONUS-based, long-range bombers. While proven very effective in Desert Storm, this triad has several limitations.[2] First, the aircraft carrier fleet is limited. Naval aviation lacks stealthy vehicles

and long-range systems.[3] Carriers will increasingly be called on for global presence missions, but cannot be everywhere at once.[4] Second, land-based fighters require forward basing, which could take days or even weeks to develop before employment. Finally, long-range manned bombers require supporting tankers, have limited loiter time over long distances, varying degrees of penetration capability, and can require up to 48 hours to prepare for strikes.[5] In 2025, these limitations will have a greater effect on US power projection as a result of two factors: the shrinking military budget and a smaller military force (fig. 3-1).[6]

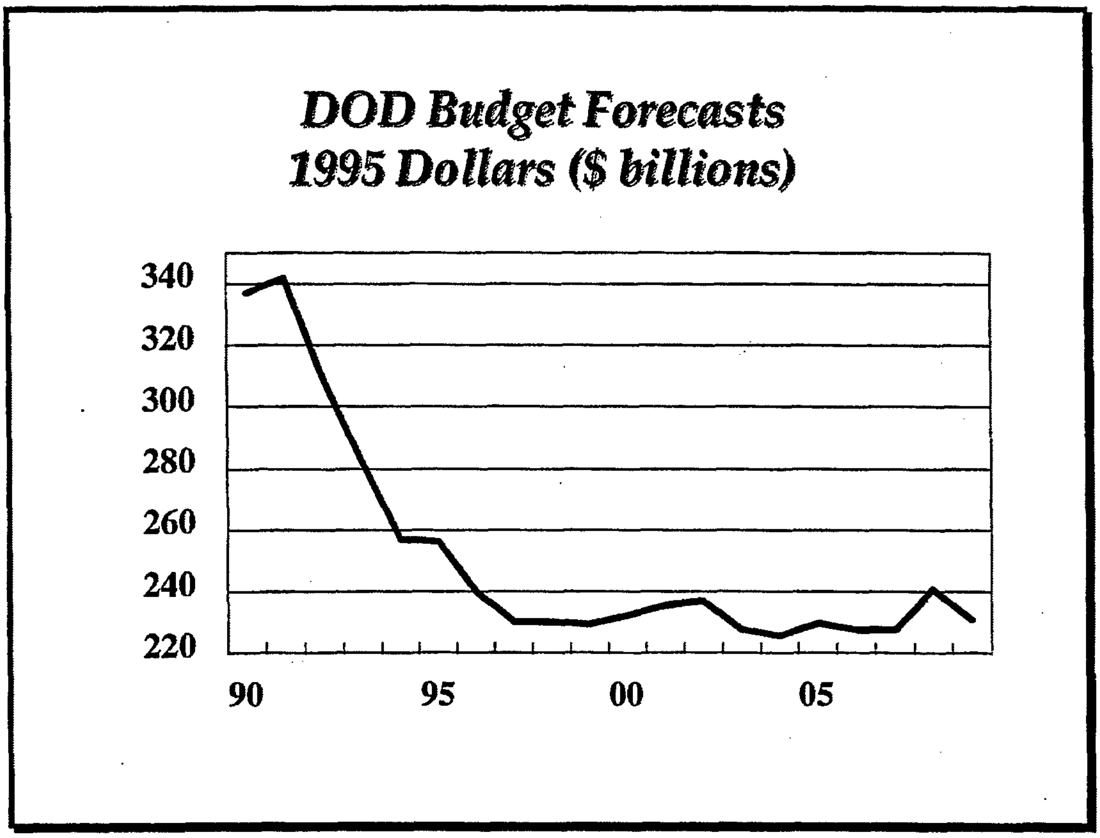

Figure 3-1. The Shrinking Military Budget

The ripple effects of current US government budgetary problems are just beginning to affect US military force levels and strength. Tighter military budgets will continue through 2010, or longer, and fewer new strike aircraft purchases will result as costs increase.[7]

Figure 3-2 represents a possible fighter force of 450 by the year 2025 and takes into consideration one of the alternate futures that might be faced.[8] It is likely that today's fighter force will be retired by 2018, the

F-22 will begin entering retirement in 2025, and that there will be further reductions in the bomber fleet. These actions will result in a 2025 triad of conventional aerospace strike forces one fourth of the size of the 1996 force.[9]

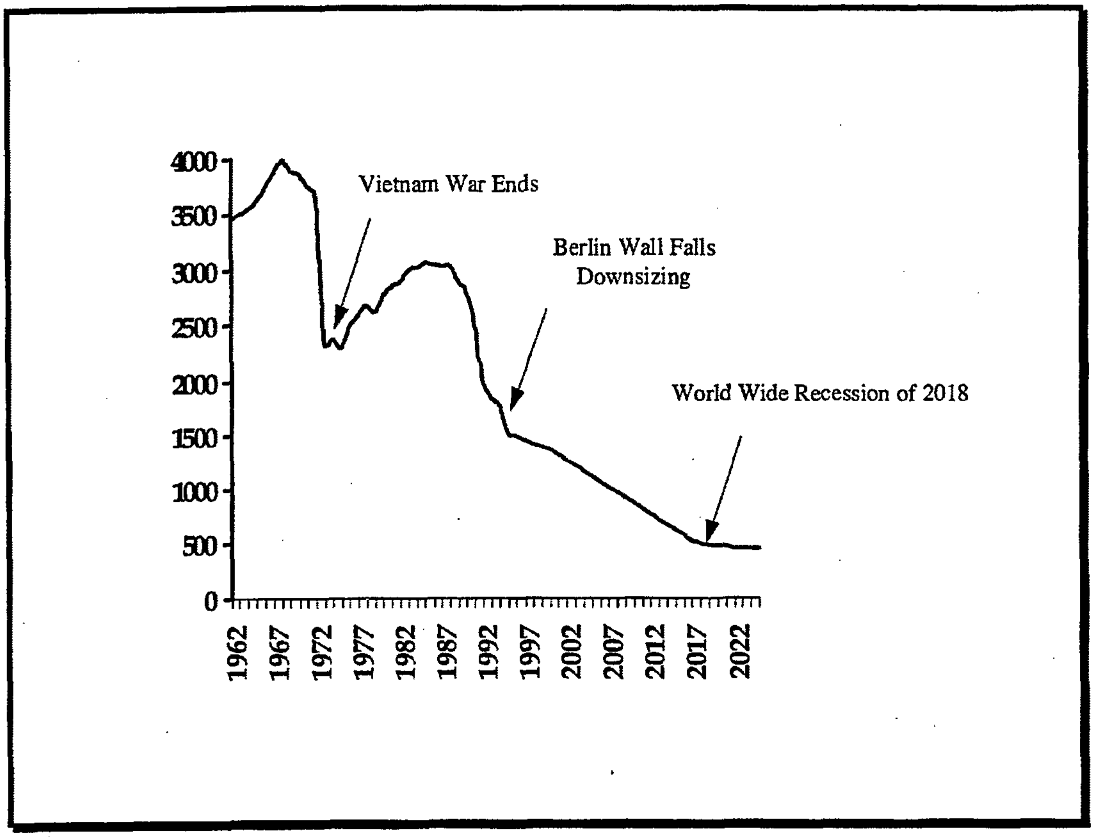

Figure 3-2. Fighter Force Projection for 2025

Unfortunately, the demands on this smaller force will not diminish. To be effective in 2025, our smaller conventional aerospace triad will require a force multiplier that will enable the US military to strike within seconds of opportunities. One way to achieve these results is to get inside our adversary's observation-orientation-decision-action (OODA) loop while reducing the time required for us to observe, and then act.[10] The advent of the capability for dominant battlespace awareness allows us the ability to significantly reduce our observation, orientation, and decision phases of the loop.[11] Unfortunately, our current triad of conventional aerospace forces are time-limited in many scenarios due to deployment, loiter, risk, and capability constraints. The concept of a long-loiter, lethal UAV orbiting near areas of potential conflict

could allow us to significantly reduce the OODA loop action phase. In fact, the entire OODA loop cycle could be reduced from days or hours to literally seconds.[12] The lethal UAV offers a variety of unique capabilities to the war fighter at the strategic, operational, and tactical levels of war.

The US strategic triad possesses the capability to hold other countries at risk with a very short (30 minute) response time, but unfortunately, this type of deterrence is only effective against forces similarly equipped. With the exception of current no-fly zones in Iraq and Bosnia, we normally do not have conventional aerospace forces posed for immediate precision strike, nor do we have the capability to exercise this option beyond one or two theaters. Although no-fly zones in Iraq and Bosnia are considered successful operations, the operations tempo and dollar cost of maintaining this deterrence is high. In 2025, a smaller, conventional aerospace triad will be expected to react within seconds over the broad spectrum of conflict from military operations other than war (MOOTW) to major regional conflict (MRC); overcome improved enemy air defense systems; and meet demands for fewer pilot and aircraft losses, all without requiring extremely high operational tempos.[13] These expectations will demand the development of a force multiplier to overcome the current, conventional aerospace triad limitations.

Required Capability

The force multiplier required for 2025 conventional aerospace triad forces must be capable of exercising the airpower tenets of shock, surprise, and precision strike while reducing the OODA-loop time from observation to action to only seconds. Also, this force must possess the capabilities of stealth for survivability and reliability for a life span equivalent to that of manned aircraft. Many possibilities exist across the spectrum of conflict. This paper develops the concept of a stealthy, reliable UAV capable of precision strike. StrikeStar could act as a force multiplier in a conventional aerospace triad one fourth the size of the 1996 force structure.

The StrikeStar UAV could add a new dimension to the war fighter's arsenal of weapons systems. In a shrinking defense budget, it might be a cheaper alternative to costly manned strike aircraft if today's high altitude endurance UAVs are used as a target cost guide. StrikeStar must rely on a system of reconnaissance assets to provide the information needed for it to precisely and responsively deliver weapons on demand. To

save costs and minimize the risk of losing expensive sensors, StrikeStar itself should have a minimal sensor load. The robust, expensive sensors will be on airborne and space reconnaissance vehicles, feeding the information to the UAV. An air or ground command element located in the theater of operations or continental United States could receive fused reconnaissance data and use it to direct the StrikeStar to its targets. A secure, redundant, communications architecture would connect StrikeStar and the command element, but the communications suite could be rather minimal since the UAV would normally be in a receive-only mode to reduce detectability.

StrikeStar should have a minimum 4,000-pound payload so a variety of all-weather weapons could be employed by the UAV, depending on the target and the effect desired. Lethal weapons could include global positioning satellite (GPS)-guided, 250-pound conventional weapons that would have the effect of current 2,000-pound weapons. Nonlethal weapons such as "Stun Bombs" producing overbearing noise and light effects to disrupt and disorient groups of individuals could also be delivered. Target-discriminating, area-denial weapons, air-to-air missiles, and theater missile defense weapons could be employed to expand StrikeStar's potential applicability to other mission areas. Finally, the best lethal weapon for StrikeStar might be an all-weather directed energy weapon (DEW) which could allow hundreds of engagements per sortie.

StrikeStar would be designed for tremendous range, altitude, and endurance capabilities. Cruising at 400 knots true airspeed, StrikeStar would have an unrefueled range of almost 17,000 nautical miles, thus minimizing the historical problems inherent in obtaining overseas basing rights that have limited our strategic choices. Translated into a loiter capability, StrikeStar could launch, travel 3,700 miles to an orbit area, remain there for 24 hours and then return to its original launch base. With a cruise altitude above 65,000 feet and a maximum altitude of 85,000 feet, StrikeStar could fly well above any weather and other conventional aircraft. It would fly high enough to avoid contrails and its navigation would not be complicated by jet stream wind effects.

Such capabilities should easily be possible by 2025. Before the year 2000, today's Tier II+ UAV will have reached nearly the StrikeStar range/endurance and payload capabilities and the Tier III- will have demonstrated stealth UAV value. The issue then revolves around the use of such an unmanned capability and how such a capability could add value to *aerospacepower* of the twenty-first century. Ben Rich, a former president of Lockheed's "Skunk Works" saw the future of the unmanned strike vehicle:

> But even a leader able to whip up sentiment for "sending in the Marines" will find it dicey to undertake any prolonged struggle leading to significant casualties. . . . As we proved in Desert Storm, the technology now exists to preprogram computerized combat missions with tremendous accuracy so that our stealth fighters could fly by computer program precisely to their targets over Iraq. A stealthy drone is clearly the next step, and I anticipate that we are heading toward a future where combat aircraft will be pilotless drones.[14]

Coupled with the ability to reduce casualties, StrikeStar and its supporting reconnaissance and communications assets will add new meaning to what the Joint Chiefs of Staff call precision engagement:

> Precision engagement will consist of a system of systems that enables our forces to locate the objective or target, provide responsive command and control, generate the desired effect, assess our level of success, and retain the level of flexibility to reengage with precision when required. Even from extended ranges, precision engagement will allow us to shape the battlespace, enabling dominant maneuver and enhancing the protection of our forces.[15]

Milestones

Currently, technology is being developed to accomplish this concept. While the technology will exist by the beginning of the twenty-first century, transferring this technology from the laboratory to the battlefield will require reaching three new milestones in aerospace thinking.

First, US military leadership must be willing to accept the concept of lethal UAVs as a force multiplier for our conventional aerospace triad of 2025. They should not deny the opportunity for continued growth in this capability.[16] The issue revolves around the use of an unmanned capability and how such a capability could add value to *aerospacepower* of the twenty-first century.

Second, doctrinal and organizational changes need to be fully explored to ensure this new weapon system is optimally employed. In the context of a revolution in military affairs (RMA), developing a new weapon system is insufficient to ensure our continued prominence. We must also develop innovative operational concepts and organizational innovations to realize large gains in military effectiveness.[17]

Finally, a target date not later than 2022 should be set for this refined concept and supporting systems to be operational for combat employment. This will give the US military and contractors time needed to correct deficiencies, leverage new technological developments, and polish capabilities equivalent to or beyond the manned portion of the conventional aerospace triad.[18] The need will exist in 2025 for a cost-effective, reliable force multiplier for the US military aerospace forces. StrikeStar offers a unique combination of

these three requirements and now is the time to begin working toward these milestones to meet conventional aerospace triad needs in 2025.

Notes

[1] Gene H. McCall, Chairman USAF Scientific Advisory Board, presentation to the AF 2025 Study Group, Maxwell AFB, Ala., 6 September 1995.

[2] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey Summary Report* (Washington, D.C., 1993), 15.

[3] John T. Correll, "Deep Strike," *Air Force Magazine*, April 1996, 2.

[4] James A Lasswell, " Presence - Do We Stay or Do We Go?," *Joint Forces Quarterly*, Summer 1995, 84–85; Col Walter Buchanan, JCS/J3, "National Military Command Center," presentation to Air Command and Staff College, 27 February 1996.

[5] Maj David W. Schneider, "Heavy Bombers Holding the Line," *Air Power Journal*, Winter 1994, 45–52.

[6] Col William Jones, JCS/J8, "JROC and the Joint War fighting Capabilities Assessment Process," presentation to Air Command and Staff College, 12 February 1996.

[7] David R. Markov, "The Aviation Market Goes Global," *Air Force Magazine*, June 1995, 22–28. In this article Mr Markov paints a gloomy picture of total strike aircraft production worldwide due to lower defense budgets and rising costs.

[8] "AF 2025 Alternate Futures: Halfs and Have Naughts," April 1996.

[9] "A New Defense Industrial Strategy," *Air Power Journal*, Fall 1993, 18–22; Brian Green, "McCain's Rising Star," *Air Force Magazine*, April 1996, 9. In this article, Senator John McCain states, "It's obvious we're not going to maintain the force structure that was anticipated when the two-MRC scenario was designed."

[10] John R. Boyd, "The Essence of Winning and Losing," presentation to the AF 2025 Study Group, Maxwell AFB, Ala., October 1995.

[11] "Warfighting Vision 2010: A Framework for Change," (Ft. Monroe, Va: Joint Warfighting Center, 1 August 1995), 10–11.

[12] Maj James P. Marshall, *Near-Real-Time Intelligence on the Tactical Battlefield*, (Maxwell AFB, Ala.: Air University Press, January 1994), 100. In this report, Maj Marshall proposes a wide range of target lifetimes ranging from several hours to one minute.

[13] Clark A. Murdock, "Mission-Pull and Long-Range Planning," *Joint Forces Quarterly*, Autumn/Winter 94–95, 33. Mr Murdock identifies 12 operating environments, more than 60 military missions, and more than 200 critical tasks by the year 2011.

[14] Ben R. Rich, *Skunk Works* (N.Y.: Little, Brown and Company, 1994), 340.

[15] *Joint Vision 2010*, (Washington, D.C.: The Joint Chiefs of Staff 1995), 9.

[16] Jeffrey Cooper, Another View of Information Warfare: Conflict in the Information Age, SAIC, (Publication Draft for 2025 Study Group), 26. In reference to new technologies he states: "These changes, exactly because they are fundamental, threaten all the vested interests and military "rice bowls," from resource allocation, to roles and missions, to the very nature of command and how control is exercised"; Gene H. McCall, Chairman USAF Scientific Advisory Board, presentation to the AF 2025 Study Group, Maxwell AFB, Ala., 6 September 1995. Dr McCall stated in his presentation: "Most revolutionary ideas will be opposed by a majority of decision makers."

[17] Jeffrey McKitrick et al., "The Revolution in Military Affairs," in Barry R. Schnieder and Lawrence E. Grinter, eds., "Battlefield of the Future: 21st Century Warfare Issues" (Maxwell AFB, Ala.: Air University Press, September 1995), 71–75; Andrew F. Krepinevich, Jr., "The Military Technical Revolution:

A Preliminary Assessment," (Maxwell AFB, Ala., Air Command and Staff College, War Theory Course Book, Volume 3, September 1995), 163.

[18] Gene H. McCall, Chairman USAF Scientific Advisory Board, presentation to the AF 2025 Study Group, Maxwell AFB, Ala., 6 September 1995. Dr McCall stated in his presentation: "Early applications of revolutionary concepts should not be required to be complete and final weapon systems."

Chapter 4

Developmental Considerations

The end for which a soldier is recruited, clothed, armed, and trained, the whole object of his sleeping, eating, drinking, and marching is simply that he should fight at the right place and the right time.

–Carl von Clausewitz *On War*

Clausewitz's statement of the supremacy of purpose for all that we do in the military applies as much today as it did centuries ago. In his day, military leaders concerned themselves with tailoring, building, and sustaining their forces to "fight at the right place and the right time" with the purpose of winning wars. Today, our leaders are faced with a similar challenge. In our increasingly technological age, military leaders are challenged to develop weapon systems that enable our forces to determine the "right place" and move people, equipment, and supplies to be able to fight at the "right time."

Unmanned aerial vehicles offer military leaders the ability to use *Global Awareness* to more accurately apply *Global Reach* and *Global Power* when and where needed. For years, UAVs have had the capability to push beyond the realm of observation, reconnaissance, and surveillance, and assume traditional tasks normally assigned to manned weapon systems. However, several factors influenced decisions that favored manned aircraft development at the expense of UAVs. A 1981 Government Accounting Office report "alleged inefficient management in the Pentagon in failing to field new [UAV] vehicles. The GAO noted several explanations for the inertia: many people are unfamiliar with the technology, unmanned air vehicles are unexciting compared to manned vehicles, the limited defense budget, and user reluctance—the pro-pilot bias."[1]

Whether one accepts this assessment or not, there have been limited advancements in military UAV development, but not without prompting from external sources. Since 1981, the US Department of Defense has expended a much greater effort in developing, producing, and employing UAVs in the reconnaissance role. In fact, UAVs proved to be a viable force multiplier in the coalition military efforts in the 1991 Gulf War.[2] However, some of those problems identified by the 1981 GAO report continue to exist today and, without additional UAV research and education, may severely limit future development of UAV military potential.

Moreover, the "jump" from using UAVs in nonlethal reconnaissance roles to lethal offensive operations is a dramatic change, adding another consideration to deal with—public accountability. It is likely the American public and international community will demand assurances that unmanned UAVs perform at least as safely as manned aircraft. This requirement must be considered in designing, developing, and employing any lethal UAVs.

This section analyzes this accountability issue and two other considerations: (1) an alleged pro-pilot bias that favors development and employment of manned aircraft over UAVs and; (2) a reduced budget that forces choosing space-based or air-breathing systems in a zero sum battle for military budget dollars.

Pro-Pilot Bias

Under the many challenges of their rapidly changing environment, the Air Force leadership may have become more focused on the preservation of flying and fliers than on the mission of the institution.

—Carl A. Builder
The Icarus Syndrome

Nearly every research effort conducted on UAV development in the last 10 years has either referenced or implied the existence of a "pro-pilot bias." None of those studies, however, defines what constitutes that bias, except in one case where it is described as a "user reluctance."[3] Yet authors state or imply that this bias has been responsible for delaying or undermining efforts in developing and employing operational UAVs since their inception. In the future, to ensure optimization of combat UAVs, underlying concerns must be identified, validated, and dealt with as hurdles to be overcome, not biases.

There are three identifiable concerns that will be analyzed concerning "pro-pilot bias" and its effects on UAV development. First, there is a skepticism that current UAV technology provides the reliability, flexibility, and adaptability of a piloted aircraft.[4] Basically, this perception implies that UAVs are incapable of performing the mission as well as equivalent manned aircraft since they are unable to respond to the combat environment's dynamic changes. This incorrectly assumes all UAVs operate autonomously as do cruise and ballistic missiles. These latter systems do lack flexibility and adaptability, and only do what they are programmed to do. Other UAVs, like the Predator, are remotely piloted vehicles, and are as flexible and adaptable as the operator flying them. The operator's ability to respond to the environment is dependent on external sensors to "see" and "hear" and on control links to provide inputs to and receive feedback from the UAV. Future UAVs using artificial intelligence will respond to stimuli in much the same way as a human, but will only be as flexible and adaptable as programmed constraints and sensor fusion capabilities allow.

In 2025, technology will enable near-real-time, sensor-shooter-sensor-assessor processes to occur in manned and unmanned aircraft operations. The question is not whether either of these systems is flexible and adaptive but whether it is more prudent to have a human fly an aircraft into a hostile or politically sensitive environment, or have an operator "fly" a UAV from the security of a secure site.

Second, there is a perception that UAVs capable of performing traditional manned aircraft missions are a threat to the Air Force as an institution. This perception is deeply rooted in the Air Force's struggle with its own identity, a struggle lasting since the early Army Air Corps days. Carl Builder, in *The Icarus Syndrome*, describes how the Air Force sacrificed airpower theory ("the end") in exchange for the airplane's salvation ("the means") when challenged by arguably more capable "means."[5] Like the intercontinental ballistic missile (ICBM) and cruise missile, the Air Force has struggled against the development of UAVs only to accommodate it when faced with other services' infringement on traditional Air Force missions. Like the ICBM and cruise missiles before it, the UAV has been assigned a support role, primarily in reconnaissance. The problem, according to Builder, is that the Air Force, when faced with challenges to the "flying machine," tends to accommodate new systems instead of adapting doctrine to tie the new "means" to its mission and underlying airpower theory.[6] Thus, Builder asserts the Air Force has been myopic, seeing the "mission" of the Air Force in terms of airplanes, and therefore any system other than an airplane is relegated to mission support, or deemed a threat to the Air Force institution and dismissed. Ironically, the UAV is

following the same development path that the airplane took over 50 years ago when the Army culture relegated it to a reconnaissance and mission support role.

Finally, there is a concern among the Air Force's pilot community that UAVs pose a threat to their jobs and, ultimately, their future Air Force roles.[7] There is a perception that UAVs will replace the need for pilots to employ aerospacepower, and closely tied to this belief is the resultant threat to the power base and leadership role pilots have held in the Air Force since its birth. It is easy to rationalize an Air Force founded on flying airplanes led by those who fly them. For years, those who protected the preeminence of the airplane also protected the leadership of the pilots and operators, sometimes at the expense of the institution's well being.[8] If it is right for pilots to lead a "fly, fight, and win" Air Force, then would it be equally right for pilots to step down when the airplane is replaced by cruise missiles, space-based platforms, and UAVs? Pilots, who have held the leadership reins of the Air Force for more than 50 years, are now faced with being replaced with specialists and technologists. This threat and the reaction of today's pilot-laden Air Force leadership will play a major role in determining the UAV's development between now and 2025.

Budget Competition — Space-Based, Air Breather, or Both

> *Space warfare will likely become its own warfare area only when there is need to conduct military operations in space to obtain solely space-related goals (not missions that are conducted to support earth-based operations).*
>
> —Jeffrey McKitrick
> The Revolution in Military Affairs

The Air Force is looking to both space and the inner atmosphere for ways to meet future war fighting requirements. At the same time, budget constraints are forcing the Air Force to be selective in determining which system(s) will receive increasingly dwindling dollars. In the past, UAVs lost similar competitions to manned aircraft in the Air Force's constant attempt to modernize its manned aircraft. Future competitions will still face manned aircraft concerns, but the competition will also be between the UAV and an equivalent space-based platform. This section does not provide a thorough comparative analysis of space-based systems and the StrikeStar. It does provide those who will make the decisions that fund one or both of these

systems with (1) an understanding that a competition exists between space-based systems and a StrikeStar concept; (2) some considerations to be used in making those decisions; and (3) recommendations for using the StrikeStar in conjunction with a bolstered space-based system.

Several organizations associated with the Department of Defense's research and development circle are developing space-based systems that can deliver precision lethal and nonlethal force against ground-based targets. Like StrikeStar, these systems have the capability to project power to any point on the earth and do so with a minimal sensor-to-shooter time delay. As orbiting systems, these systems provide decision makers a near continuous coverage of all global "hot spots." In many respects, these systems parallel capabilities provided by a gravity-bound StrikeStar.

Unlike StrikeStar, space-based systems are expensive in research and development, and the space environment provides operational challenges. The budget dollars do not exist now and likely will not exist in the future to fund the simultaneous development of space-based and StrikeStar UAV systems. But more important than lack of money is the waste inherent in simultaneously developing systems that duplicate each other's capabilities without adding any appreciable value.[9] For years, the Navy and Air Force have done just this by developing very similar frontline fighters. Today, the services and Congress understand that this practice results in great waste and that they can reduce that waste by comparing space-based attack system and UAV development now and determining which strategy will best provide needed capabilities by 2025.

Decision makers must compare space-based and air-breathing systems and determine which will receive development funding. They must consider the capabilities, limitations, and implications of both systems and form a conclusion as to which system or combination of systems provides the needed war fighting capability in 2025. Probably the greatest limitations of space-based systems are the costs associated with transporting the vehicle from the surface to earth's orbit, maintaining it (in orbit or on return), and then transporting it back to the surface. Another significant space-based system limitation is the criticality of the vehicle(s) position or orbit. Space-based systems cannot currently loiter over a target area since orbital mechanics require constant movement around the earth. Therefore, a space-based system needs multiple vehicles to provide constant coverage as well as the ability to position a vehicle when and where needed.

Decision makers must also consider the sociopolitical implications of militarizing space. Some argue control of space is analogous to control of air and that this new frontier should be approached in the same

manner the military approached airpower.[10] But this new frontier is inherently different from the skies overlying the earth's nations, and space cannot be divided up in segments as the international community has done with airspace. In fact, space is rapidly being established as an international domain for commercial interests owned by a combination of nation-states and corporate conglomerates. Establishing space dominance will be costly and threatening to an increasingly interdependent international community. Placing an offensive-capable platform in space that continuously holds any nation or group of individuals at risk will undoubtedly be perceived as a direct threat to friendly or enemy nations.

A less threatening alternative for space is the enhancement of current military capabilities in the areas of reconnaissance, navigation, and communications with concurrent development of space-to-space weapon systems designed to protect our space-based assets. Also, challenges associated with projecting lethal and nonlethal force from space-to-surface targets may be too difficult and costly when compared with inner-atmosphere systems with similar capabilities. Offensive and defensive space-based systems are essential, but primarily for missions that support space requirements and not for direct attack against inner-atmosphere targets.

Probably the greatest limitation of air-breathing UAVs compared to an equivalent space-based system is the time delay required to mobilize and deploy it to a theater of operations. StrikeStar is designed to deploy-loiter-strike-loiter-redeploy from either CONUS or a forward base, but due to fuel limitations, the time required to deploy and redeploy are contingent on the distance to the area of operations and this also directly affects available loiter time. Because StrikeStar cannot stay airborne indefinitely, it may require advanced warning times or an increased number of vehicles to provide continuous coverage of the operations area.

Because of high costs to develop, operate, and maintain space-based systems that might deliver lethal force on the earth's surface, the armed forces should tailor development of space-based platforms to lethal missions that focus on space-only missions and nonlethal missions supporting earth-bound lethal weapon systems. StrikeStar and a new generation of UAVs capable of delivering lethal and nonlethal force provide a low cost, highly mobile platform that will enable the US military and civilian authorities to project power to any point on the globe in minimal time and hold an area at risk for days at a time. StrikeStar is not a threat to space, but simply provides an effective capability that when directed by air, land-based, or space-based command and control can reach out and touch enemies threatening our national interests throughout the world.

Public Accountability

War is a human endeavor, fought by men and women of courage. The machines, the technology help; but it is the individual's skill and courage that makes the crucial difference.

—General Gordon R. Sullivan
Army Focus 1994: Force XXI

The public will demand accountability for lethal UAVs and their operations and StrikeStar's lethal potential requires assurances that prevent inadvertent or unintentional death and destruction to both friendly and enemy troops.

Imposed Limitations

Restrictions must be placed on lethal UAVs because of the potential consequences of an accident or malfunction. Recent history has proven that the American public and the international community hold individuals and organizations accountable for decisions to use force. The downing of two US helicopters supporting Operation Provide Comfort in Northern Iraq and the subsequent loss of 24 lives provide a vivid example of how the public will react to lethal force "accidents" or "mistakes." Today, accident-or mistake-justifications do not warrant death or destruction.

Even in war, use of legitimate lethal force will be questioned. Society has become more sensitive to death and destruction as the information age provides real-time, world-event reporting. Television presents images and political commentary, probing and demanding justification for using lethal force. The intent of those inquiries is to determine accountability when events result in questionable death or destruction. Also, technology has legitimized precision warfare, and "criminalized" collateral death and destruction resulting from the use of lethal force. The perception exists among many press and public that it is now possible to prevent nearly all types of accidents and mistakes and only shoot the "bad guy."

These perceptions place limits on using any system that could deliver lethal force. StrikeStar falls within this category and it is imperative that accountability be built into the system design and concept of operations.

But how do we create accountability? First, a human must be involved in the processes that result in lethal force delivery. Second, redundancy must be designed into the system to ensure a person can exercise control from outside the cockpit. Third, the system must be responsive to the dynamic environment in which it will operate. Finally, reliability must be designed into every StrikeStar system and subsystem to minimize the possibility of inadvertent or unintentional use of lethal force. In total, these measures place a human in the decision-making position when employing lethal force. Thus, when an accident or mistake occurs, a person, not a machine, is responsible and accountable. For claiming a system failure, or "it just blew," will not suffice.

Man-in-the-Loop

Accountability is not well suited for anything other than a person. When an aircraft crashes, the mishap board's task is to find causal reasons for the crash. Even when it becomes apparent a broken or malfunctioning part contributed to the crash, the board probes the processes involved in its production, installation, and even documentation. Since processes are created and normally managed by people, accountability is normally given to a person.

So humans must be involved in the decisions that could result in intentional or unintentional death and destruction. But human input is not required in all phases of flight and there are various ways to keep a person in the loop without putting a pilot in a cockpit. However, because of the potential consequences of mistakes or accidents, human input must be involved in target selection and weapons delivery decisions.

The man in the loop can be attained through nearly all of the potential controlling mechanisms available now and forecast into the future. UAV control mechanisms included manned, remotely piloted, semi-autonomous (combined RPV and programmed), autonomous (programmed/drone), and fully adaptive (artificial intelligence). StrikeStar control mechanisms allow for inflight human input, but an autonomous system preprogrammed to hit a prelaunch designated target or target area with minimum human intervention and not normally be changed in flight could be used. Also, a fully adaptive UAV using artificial intelligence could be programmed to mimic the decisions a pilot would make in reacting to environmental changes.

Although it can be suited to some missions, a lethal UAV with autonomous or fully adaptive controls pose significant accountability problems. First, decisions to target and strike are made without regard to a

rapidly changing environment. For example, a tomahawk land attack missile (TLAM) might hit a command post even though, in the time since it was launched, a school bus full of children stopped nearby. An autonomous system has no way of knowing current or real-time information that may affect the decision to target and strike. Second, autonomous UAVs cannot react to internal malfunctions that might affect their ability to perform their prescribed missions. A preprogrammed UAV told to deliver its weapon will do so even though its targeting system has malfunctioned and the result is a bomb dropped with unknown accuracy. The net effect in both situations is inadvertent or unintentional delivery of lethal force and an accountability question.

Obviously, 100 percent reliability is not guaranteed even with a human in the decision making process, but 100 percent accountability must be attempted. The further a person gets away from lethal force accountability, the easier the "fire" decision is and the greater the probability that the wrong target will be hit. As a result of this tendency and the severity of the consequences, our air-to-air rules of engagement favor visual identification over system interrogation and identification. A person must be kept in the loop when using UAVs to deliver lethal force.

Redundancy

To keep man in the loop and maintain this accountability, we must ensure the control links are sufficiently redundant. There are two potential centers of gravity that, if intentionally or unintentionally targeted, would remove or degrade the man in the loop. First, the control links are susceptible to MIJI (meaconing, intrusion, jamming, and interference). In this case, the "lines" between the UAV and the controller are severed or degraded to a point where the UAV is basically autonomous. Second, the controller or the controllers' C^4I facilities are also susceptible to physical destruction, equipment malfunctions, and situational dis/misorientation. In this case, the source of the signals or an intermediary relay (e.g., satellite) would be physically incapable of sending or transmitting control signals to the UAV. In either case, the UAV is without a man in the loop.

Controller backup systems need to be able to deal with contingencies that could threaten the UAV's ability to accurately hit its designated target. The StrikeStar should have triple redundancy built into the controlling system utilizing a ground source, airborne source, and an autonomous backup mode. Should the

UAV detect an interruption of controller signals, it could enter an autonomous mode and attempt to reconnect to its primary controller source. If unable to reconnect, it could search for a predesignated secondary controller input and establish contact with the backup controller. The final option available if the UAV can not regain controller input would be to follow the last known program or abort, depending on its prelaunch abort configuration.

Responsiveness

The StrikeStar system must be responsive to a dynamic environment and design must include flexible C^4I systems, C^2 operations, and UAV guidance and fire control systems. It is imperative that a lethal UAV be able to assess its environment and adapt to it accordingly. This requires real-time data and assessment, high-speed data transmission capability, flexible C^2 procedures, reliable controller capability, and a real-time reprogramming capability.

An advantage of a manned aircraft is that the pilot can make the last-second decision to deliver the weapon, abort the delivery, or change targets as the situation dictates. At the last-second, a pilot can detect an unknown threat preventing him or her from reaching the target, and has the ability to change targets when the original target has moved. Simply, a pilot has the ability to assess and react to a environment characterized by fog and friction.

Lethal UAVs (and/or their controllers) must have the same ability to adapt to an unanticipated or dynamic environment. They must be able to discern the environment, consider the threat (in cost-benefit terms), confirm the intended target, and have the ability to deliver, abort, or change to a new target. The consequences of not having this ability relegates the UAV to an autonomous system and raises accountability questions in the event of an unintentional or inadvertent delivery. Real-time information and control is essential to protecting our accountability in lethal UAVs.

Reliability

The UAV and its many subsystems must have a high operational reliability rate to prevent accidental destruction and collateral damage. Unlike nonlethal UAVs, unmanned systems carrying lethal munitions

could have destructive effects in an accident or systems-related malfunction. Lethal UAVs must have a higher reliability confidence level than a manned system because UAV system malfunction effects could prove to be more disastrous.

Summary

StrikeStar as well as other systems that deliver lethal force will be scrutinized when accidents occur, especially those that result in unintentional or inadvertent loss of life or treasure. The public will demand accountability for lethal UAVs and their operations. Therefore, design, development, and employment of the StrikeStar must integrate the concept of accountability. Humans must remain in the command and control loop, and the internal and external systems and links must be robust enough to keep that loop intact. The sociopolitical implications are too high to ignore these facts.

Conclusion

Although the StrikeStar concept can be proven to meet an operational need, is technically feasible, and fits into a sound concept of operations, it may go the way of previous UAV concepts. Forces exist today that could slow or deny the development of a lethal UAV for use in 2025. Most prevalent are the historical bias for manned aircraft over UAVs, budget competition between space development and the UAV programs, and, finally, the public pressure that increasingly requires accountability when things go wrong. These forces need to be understood and met openly as we start developing a StrikeStar.

Notes

[1] David H. Cookerly, *Unmanned Vehicles to Support the Tactical War* (Maxwell AFB, Ala.: Air University Press, May 1988), 25.

[2] Lt Col Dana A. Longino, *Role of Unmanned Aerial Vehicles in Future Armed Conflict Scenarios* (Maxwell AFB, Ala.: Air University Press, December 1994), 9.

[3] Ibid., 25.

[4] Ibid., 28.

[5] Carl H. Builder, The Icarus Syndrome (New Brunswick, N.J., 1994), 200.

[6] Ibid, 205.

[7] Longino, 13.

[8] Builder, 200.

[9] Jeffrey McKitrick et al., "The Revolution in Military Affairs," in Barry Schnieder and Lawrence E. Grinter, eds., *Battlefield of the Future; 21st Century Warfare Issues* Maxwell AFB, Ala.: Air University Press, September 1995), 78.

[10] McKitrick, 89.

Chapter 5

StrikeStar Technology

> The system was so swift that human beings simply could not handle the target volume without extensive automated support, and the system was designed to fight on full automatic, relying on its human masters for key decisions, for overall guidance, for setting or revising priorities, and for defining operational parameters. Technically, this most potent warfare machine ever built had the capability to carry on the fight indefinitely.
>
> –Ralph Peters
> *The War in 2020*

The war machine described above is fiction, but the technology is within our grasp to make it a reality. In the past, UAV systems have been plagued with reliability problems or by design flaws (see appendix A).[1] Recently, the joint tactical UAV Hunter was canceled due to continuing reliability problems.[2] Current efforts are producing mature technology that improves overall reliability and functionality. The first DOD UAV master plan was produced to consolidate requirements and integrate efforts across all DOD agencies.[3] The Global Hawk and DarkStar UAVs are excellent examples of how quickly UAV systems technology is advancing. Table 1 provides a summary of US UAV characteristics from a system capabilities perspective.

Table 1

US UAVs, System Characteristics

Characteristic	Maneuver UAV	Interim Joint Tactical Pioneer	Joint Tactical Hunter	MAE Predator	CHAE UAV Global Hawk Tier II Plus	LOHAE UAV DarkStar Tier III Minus
Max Altitude (ft)	13000	15,000	25,000	25,000	>65,000	45,000
Endurance (hrs)	3	5	12	> 24	> 24	> 8
Rad. Action (nm)	27	100	> 108	500	3000	> 500
Max Speed (kts)	TDB	110	106	129	> 345	> 250
Cruise Speed	<90	65	> 90	110	345	> 250
Loiter Speed	60-75	65	< 90	70-75	340	> 250
Payload Wgt(lbs)	50	100	196	450	2,140	1287
Max Wgt	200	429	1700	1873	24,000	8,600
Navigation	GPS	GPS	GPS	GPS/INS	GPS/INS	GPS/INS

Source: *Unmanned Aerial Vehicles*, Defense Airborne Reconnaissance Office Annual Report (Washington, D.C., August 1995).

This family of UAVs capitalized on past accomplishments and started the evolutionary process of adapting technologies proven in manned aircraft to UAV platforms. Other countries are also involved in UAV technology and have recognized the roles UAV will have on future battlefields (see appendix B).[4] Trends indicate a wide range of anticipated technologies will support the StrikeStar concept and provide platform robusting. Some include:

1. airframe technology
2. avionics systems
3. propulsion technology
4. weapon systems
5. communications systems
6. mission control equipment
7. launch and recovery equipment

Sensor technologies are not critical to the construction and design of StrikeStar, but are critical to its operation. We expect reconnaissance efforts for both manned and unmanned aircraft and space platforms will continue to advance. StrikeStar will rely on other platforms for target identification, but could have the

capacity to carry reconnaissance sensors using modular payload approaches. This concept does not advocate combining expensive reconnaissance sensors on the same platform carrying a lethal payload, since separating sensors from the weapon platform lowers costs and lessens the risk of sensor loss.

The technologies noted above have to support the system characteristics shown in table 2 to ascertain current capabilities and identify enabling technologies that support the StrikeStar concept. Our baseline for the system characteristics is based on a melding of the Global Hawk and DarkStar performance attributes. The range and loiter improvements allow us to overcome the basing and response constraints mentioned in chapter 2. Adding stealth characteristics to a Global Hawk-size UAV reduces vulnerability and allows covert operation. Improved payload capacity allows the ability to carry both more and varied weapons. The envisioned altitude improvements allow for airspace deconfliction, self defense, and weapon range and dispersion performance.

Table 2

StrikeStar System Characteristics

Characteristic	StrikeStar
Wingspan (ft)	105
Max Altitude (ft)	>80,000
Endurance (hrs)	> 40
Rad. action (nm)	3700 w/24 hr loiter
Max Speed (kts)	> 400
Cruise Speed (kts)	400
Loiter Speed (kts)	400
Payload Wgt (lbs)	4000
Max Wgt (lbs)	24,000
Navigation	GPS/INS

Airframe Technology

Past UAV systems have used both fixed and rotary wing configuration. Rotary wing systems overcome many of the problems associated with launch and recovery, and optimize sensory payload operations. The Sikorsky Cypher provides a recent, successful demonstration of rotary wing technology.[5] Unfortunately, most rotary wing systems have limited range and endurance capabilities. Most UAVs fall into the fixed wing category including all those currently in-service worldwide.[6]

Typical low performance fixed wing systems employ rear-mounted pusher propellers, such as the Predator UAV, or tractor propellers. Systems have single or twin tail booms and rely on their relative small radar cross section and low noise generation to avoid detection. The Hunter platform shown in figure 5-1 is a prime example of a UAV using push-pull engine technology on a twin boom airframe.

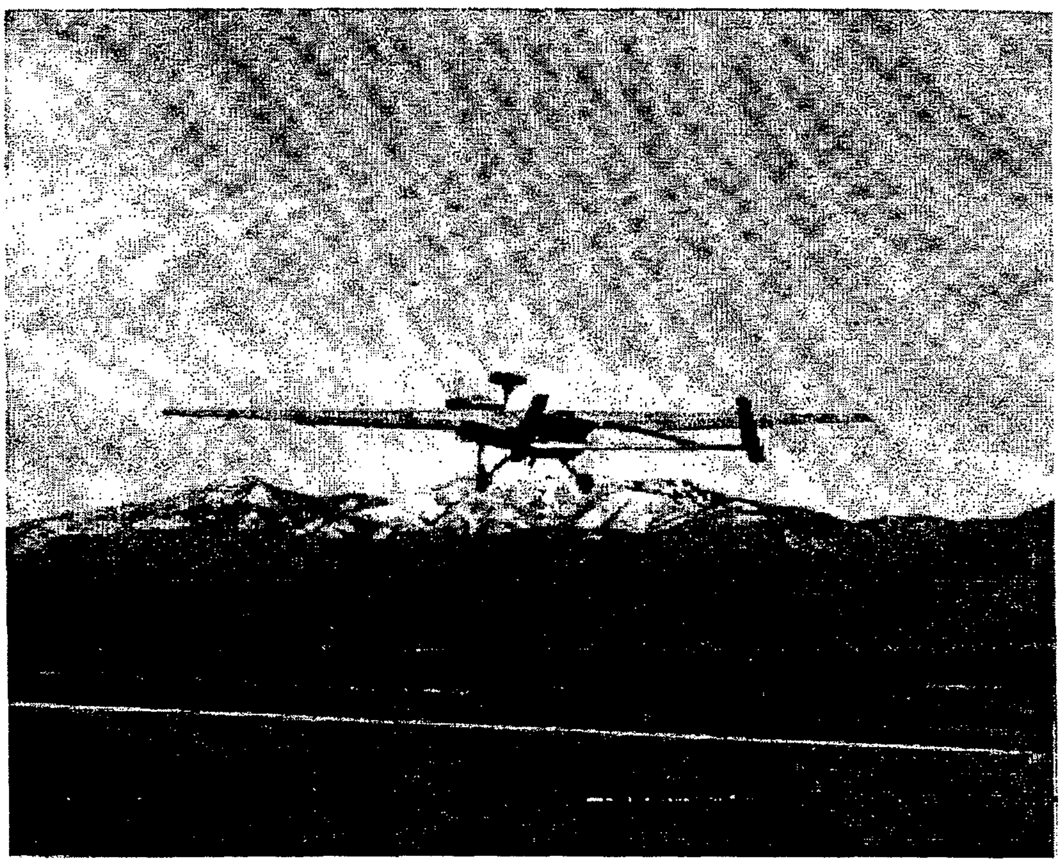

Figure 5-1. Twin-Boom Hunter UAV

Designs to date have focused on using existing manned airframe components or designs to minimize cost or produce operational platforms quickly. These systems support moderate payloads over various ranges despite known aerodynamic deficiencies. The advent of the DarkStar platform demonstrates an innovative approach to improve both aerodynamic efficiency, payload support, and operational radius.[7] DarkStar's use of a jet engine coupled with a composite flying wing structure will improve aerodynamic efficiencies and significantly decrease the radar cross section.

As currently designed, the DarkStar UAV consists of an internal payload bay capable of supporting a sensor payload which can be swapped in the field. The current payload capacity and platform configuration does not allow DarkStar to function as an efficient strike platform. Skunkworks designers are continuing evolutionary improvements on the DarkStar platform. Their conceptual design in figure 5-2 provides a look at a twin engine platform capable of increased range, speed, and payload capacity that has the potential to function as a UAV strike platform. This design could serve as the basis for future StrikeStar developments.

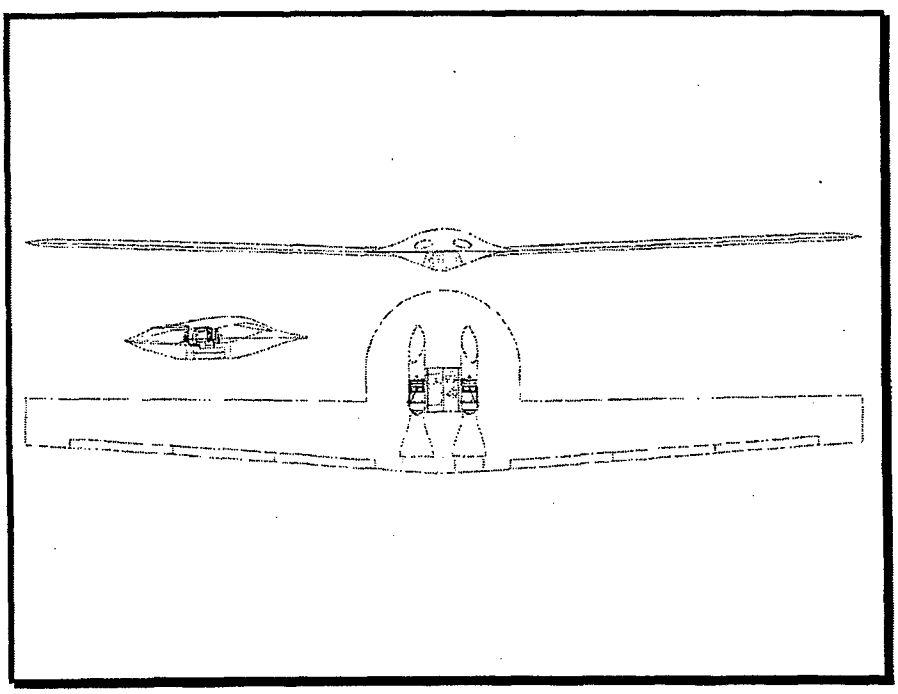

Figure 5-2. Notional StrikeStar

StrikeStar designers could capitalize on DarkStar payload swapping techniques as well as internal weapon carriage technology used for the F-117 and F-22 airframes. Future generations of StrikeStar

airframes would rely on larger payload bays and wider use of composite materials to improve payload capacity and stealthiness without increasing total weight. We anticipate that stealth technologies will mature to the point that cloaking or masking devices could be used to prevent detection or the employment of effective countermeasures.[8]

On-Board Control Systems

The avionics system would support two modes of platform operation: command-directed and autonomous. In command-directed operation, the StrikeStar operator would transmit the desired strike mission way points, cruising speed, and flight altitude to the StrikeStar flight control system to perform normal flight operations. Preprogrammed operations would be possible if all known way points were entered prior to a mission. Default preprogrammed operations would commence if uplink communications were lost and not recovered within a user-selectable time frame. Defaults could include entering preplanned holding patterns or initiating preplanned egress maneuvers as determined by the on-board Virtual Pilot system described later.

The avionics system would be based on concepts embodied in the Pave Pace integrated avionics architecture. Pave Pace is a concept that uses a family of modular digital building blocks to produce tailorable avionics packages. Using this approach on the StrikeStar would allow for future growth and allows the UAV avionics to mirror manned platform components without adding additional avionics maintenance requirements. A notional avionics system, based on the Pave Pace integrated avionics architecture is shown in figure 5-3.

The StrikeStar flight control system would rely on an integrated system consisting of a global positioning system (GPS) receiver, an inertial navigation system (INS), autopilot, and various sensing and control functions. StrikeStar navigation would rely on GPS precision "P" code data. Eventually, as potential enemies develop GPS jamming capabilities to prevent GPS use in target areas, an INS could provide redundancy and allow limited autonomous operation in the event GPS countermeasures are encountered. Other UAVs could also be used to broadcast high power, synchronous broadband satellite signals over target areas to counter GPS countermeasures.[9]

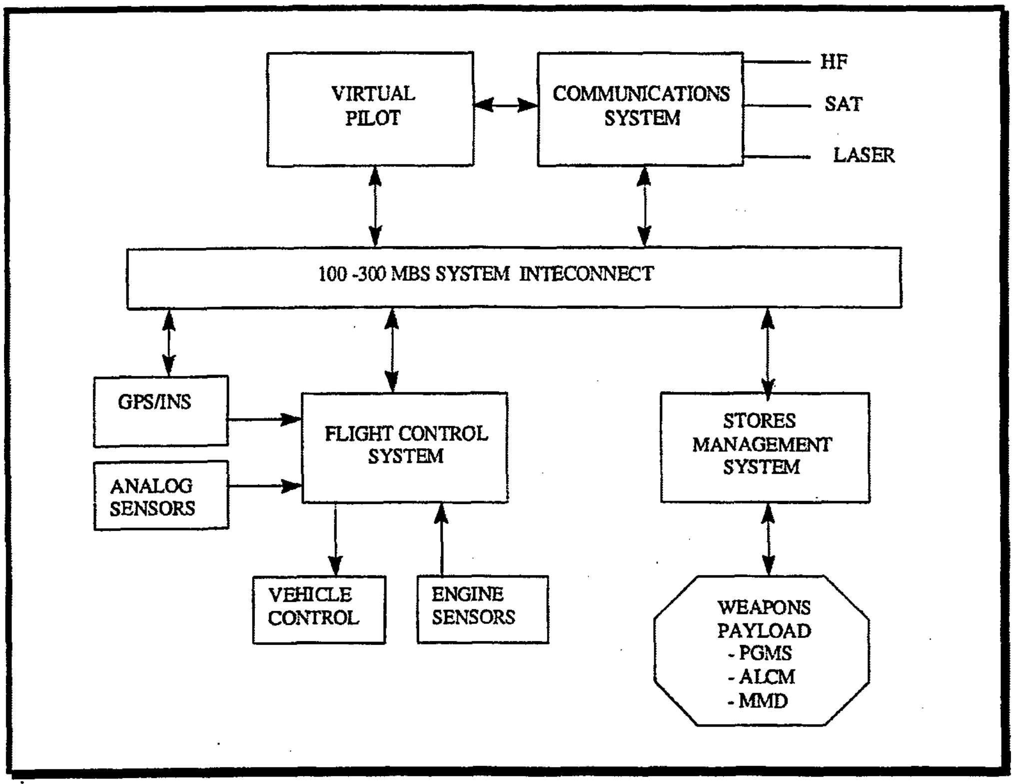

Figure 5-3. StrikeStar Notional Avionics

GPS location data could be transmitted to the control station at all times except in autonomous or preprogrammed operation. Components produced in the Tri-Service Embedded GPS/Inertial Navigation System (EGI) Program, which integrates GPS into the fighter cockpit for better navigation and weapon guidance, could be adapted for use in StrikeStar.[10] In addition to GPS data, StrikeStar would transmit altitude, airspeed, attitude, and direction to control station operators as requested.

The Virtual Pilot provides StrikeStar with a computational capability far exceeding current airborne central computer processing capabilities. Virtual Pilot would consist of an artificial intelligence engine relying on a massively parallel optical processing array to perform a wide range of pilot functions during all operational modes. In addition, the Virtual Pilot could perform self-diagnostic functions during all phases, flight operation phases, and maintenance checks. An antfratricide system would reside in the Virtual Pilot to ensure that combat identification of friendly forces is accomplished before weapon release. This would provide an additional fail-safe to any battlefield awareness systems present in the target area and allow

limited extension of a battlefield combat identification to future allies operating with US forces. StrikeStar would also be capable of interrogating and classifying identification friend or foe transponder-equipped platforms to facilitate use of that data in air-to-air engagements and identify potential airborne threats.

Propulsion System

Many current UAV systems are based on inefficient, propeller-driven airframes powered by internal combustion engines, relying on highly volatile aviation gasoline, which causes military forces significant safety and logistics issues. Propeller improvements are progressing, but the desire for stealthy platforms steers many designers away from these systems with the exception of the Predator. Gas turbine engines have been demonstrated for rotary wing applications and the use of jet engines has been widely demonstrated and proven highly effective in combat operations.[11] Significant research has been conducted on electrically powered platforms that rely on expendable and rechargeable batteries. Recently, fuel cell application research increased, as evidenced by demonstrations of the solar rechargeable Pathfinder.[12] Unfortunately battery and fuel cell systems exhibit low power and energy densities relative to hydrocarbon fuels. For that reason, internal combustion engines will continue to be the mainstay for less sophisticated UAV propulsion systems.

Jet engine design is a trade-off between airflow and fuel to maximize performance. Engine designers either enlarge the size of engine intake to increase airflow or provide more fuel to the jet engine combustion chambers to produce the desired propulsion characteristics. Since most jet engines rely on conventional fuels, designers increased intake size to maximize fuel efficiency and improve range and endurance. However, increasing UAV intake size is not desirable since this impacts the stealth characteristics and overall aerodynamic efficiencies of small airframes. Exotic or alternative fuels hold much promise for powering future aircraft and extensive research has been conducted on potential new aircraft fuels. Table 3 provides some potential aircraft fuel characteristics.

Table 3

Fuel Characteristics

Fuel	Btu/lb	Btu/cu ft	lbs/cu ft	Btu/lb of fuel
JP	18,590	940,000	50.5	0.47
Hydrogen	51,500	222,000	4.3	3.20
Methane	21,500	570,000	26.5	0.49
Propane	19,940	720,000	36.1	0.65
Methanol	8,640	426,000	49.4	0.60
Boron	30,000	1,188,000	39.6	0.57
JP from coal	18,830	996,000	53.0	0.47

Source: Senate, Hearings before the Subcommittee on Aerospace Technology and National Needs of the Committee on Aeronautical and Space Sciences, 94th Congress, 2nd sess., 27-28 September 1976.

Exotic fuels have been used for manned platforms in the past, but only in isolated cases because of the risks associated with them. Risk to man is minimized on UAV platforms except during launch and recovery cycles, and while storage of exotic fuels remains a concern, storage technology is improving. Still, exotic fuels represent a viable option for improving enthalpy on UAV platforms. Hydrogen-based fuels provide significant increases in energy density over conventional hydrocarbon fuels, and such fuels could be widely employed in UAVs by 2025 if current research advances continue and a nationwide manufacturing and distribution network emerges.

Weapon Systems

Weapons with current, precision-guided-munitions characteristics, new nonlethal weapons, and directed-energy weapons could provide StrikeStar with the capability to strike at all levels of conflict from military operations other than war to full-scale war. The key to producing a StrikeStar that can hold the enemy at risk is to deploy weapon systems that have all-weather and extremely precise aimpoint capabilities.

Precision-guided munitions are widely accepted as demonstrated during the Persian Gulf War. The family of Launch and Leave Low-level Guided Bombs (LLLGB), Maverick, and homing anti-radiation missiles (HARM) all represent current weapons that could be integrated into a UAV strike platform. Unfortunately, these weapons lack range and poor weather capability. New all-weather seekers are needed to provide desired battlefield dominance. New studies to produce long-range hypersonic PGMs are also underway, which if employed on a StrikeStar could significantly extend the weapon employment zone.[13] Efforts underway on the should produce weapons technology that not only discriminates against ground targets, but operates in adverse weather conditions.[14]

Stores management systems (SMS) used in modern attack aircraft could be integrated into UAV avionics packages to provide required weapon control and release functions. Tight coupling between sensor platforms, the Virtual Pilot and SMS could allow for autonomous weapon selection, arming , and release without operator intervention under certain scenarios. Unfortunately, the weight and large size of current PGMs and limited functionality of current SMS suites could limit conventional weapon employment.

Recent developments on an enhanced 1,000-pound warhead proved that blast performance of 2,000-pound MK-84 is obtainable.[15] Improved explosives are an enabling technology that would reduce weapon size without decreasing blast performance. Guidance and warhead improvements envisioned in the Miniaturized Munitions Technology Demonstration (MMTD) effort could produce a new class of conventional weapons. The MMTD goal is to produce a 250-pound class munition effective against a majority of hardened targets previously vulnerable only to 2,000-pound class munitions.[16] A differential GPS/INS system will be integral to the MMTD munition to provide precision guidance, and smart fusing techniques will aid in producing a high probability of target kill. The kinetic energy gained by releasing these weapons at maximum StrikeStar altitudes would also help improve explosive yield. Improving bomb accuracy, focusing on lethality, and providing an all-weather capability are all technology goals which, when coupled with a StrikeStar platform, could produce a potent strike platform. MMTD advances would significantly improve weapons loading on StrikeStar. Unfortunately, conventional explosives technology has the limitation that once all weapons are expended, the UAV must return to base for replenishment. However, StrikeStar directed energy weapons would allow more strikes and reduce replenishment needs.

Directed energy weapon (DEW) technology is undergoing rapid advances as demonstrated on the Airborne Laser program. The goal to produce a laser capable of 200 firings at a cost of less than $1,000 per shot is realizable in the near future.[17] The ability for rapid targeting, tracking, and firing of a UAV-mounted DEW could deny enemy forces the ability to maneuver on ground and in the air. If initiated now, expanded research efforts could produce a smaller, more lethal, directed-energy weapon suitable for a StrikeStar platform in 2025.

Capabilities in present air-to-air weapons provide a level of autonomous operations, which if employed on StrikeStar could revolutionize offensive and defensive counter air operations. A StrikeStar loaded with both air-to-ground and air-to-air missiles could be capable of simultaneous strike and self-defense. Additional survivability could be provided by using towed decoys cued by off-board sensors. Advanced medium range air to air missile (AMRAAM) and air intercept missile (AIM-9) weapons are proven technologies already compatible with stores management systems that could be employed on StrikeStar. Internal carriage and weapon release of these missiles from a StrikeStar could rely on experiences gained in the F-22 program. Eventually, a new class of air-to-air missiles could be developed which are significantly smaller and more lethal to allow additional weapon loading.

Nonlethal weapons also present some unique possibilities for use on the StrikeStar. Nonlethal weapons are defined as:

> discriminate weapons that are explicitly designed and employed so as to incapacitate personnel or material, while maintaining facilities.[18]

Nonlethal weapons that disorient, temporarily blind, or render hostile forces or equipment impotent, provide alternative means for neutralizing future opponents without increasing the political risk death and destruction can bring.[19] Employing these weapons from StrikeStar platforms could be used in prehostility stages to demonstrate resolve and the dominant presence of orbiting weapon platforms with instantaneous strike capabilities.

Communications Systems

"What the warrior needs: a fused real-time, true representation of the Warrior's battle space—an ability to order, respond, and coordinate horizontally and vertically to the degree necessary to prosecute his mission in that battle space."[20] To provide continuous battlefield dominance, information dominance is critical for StrikeStar operations. Battlespace awareness as envisioned under the *C^4I for the Warrior Program* will provide the information infrastructure required for command and control (C^2) of the StrikeStar platforms. UAV communications systems function to provide a communications path, or data link, between the platform and the UAV control station, and to provide a path to pass sensor data. The goal of the C^4 system is to have the head of the pilot in the cockpit, but not his body.[21]

StrikeStar communications would provide a reliable conduit for status information to be passed on a downlink and control data to be passed on the uplink in hostile electronic environments. The uplink and downlink data streams would be common datalinks interoperable with existing C^4 datalinks to maximize data exchange between sensors, platforms, and their users. Status and control information would be continually transferred between StrikeStar and its controller in all cases except during autonomous operation or implementing preprogrammed flight operations. The data link would need to be impervious to jamming, or even loss of control, to ensure weapon system integrity. User-selectable, spread spectrum, secure communications in all transmission ranges would provide redundancy, diversity, and low detection and intercept probability. Both beyond line-of-sight and line-of-sight communications methods would be supported to a variety of control stations operating from aerospace, land, and sea platforms.[22]

Command and control of UAVs via satellite links has been demonstrated to be highly reliable.[23] The MILSTAR constellation or its follow-on could serve as the primary C^2 communications network for StrikeStar platforms. MILSTAR's narrow-beam antennas coupled with broad-band frequency hopping provides isolation from jammers and a very low probability of detection.[24] The Defense Satellite Communications System (DSCS) constellation and Global High-Frequency Network could provide alternate paths for connectivity and redundancy depending on mission profiles. The vast HF network provides nearly instantaneous coverage and redundancy under adverse environmental conditions (fig. 5-4).[25] High-Frequency can provide commanders with useful, flexible, and responsive communications while reducing the demand on

overburdened satellite systems.[26] The continued proliferation of commercial satellite networks may allow StrikeStar platforms to exploit these networks as viable communications paths as long as C^2 integrity of on-board weapons is assured.

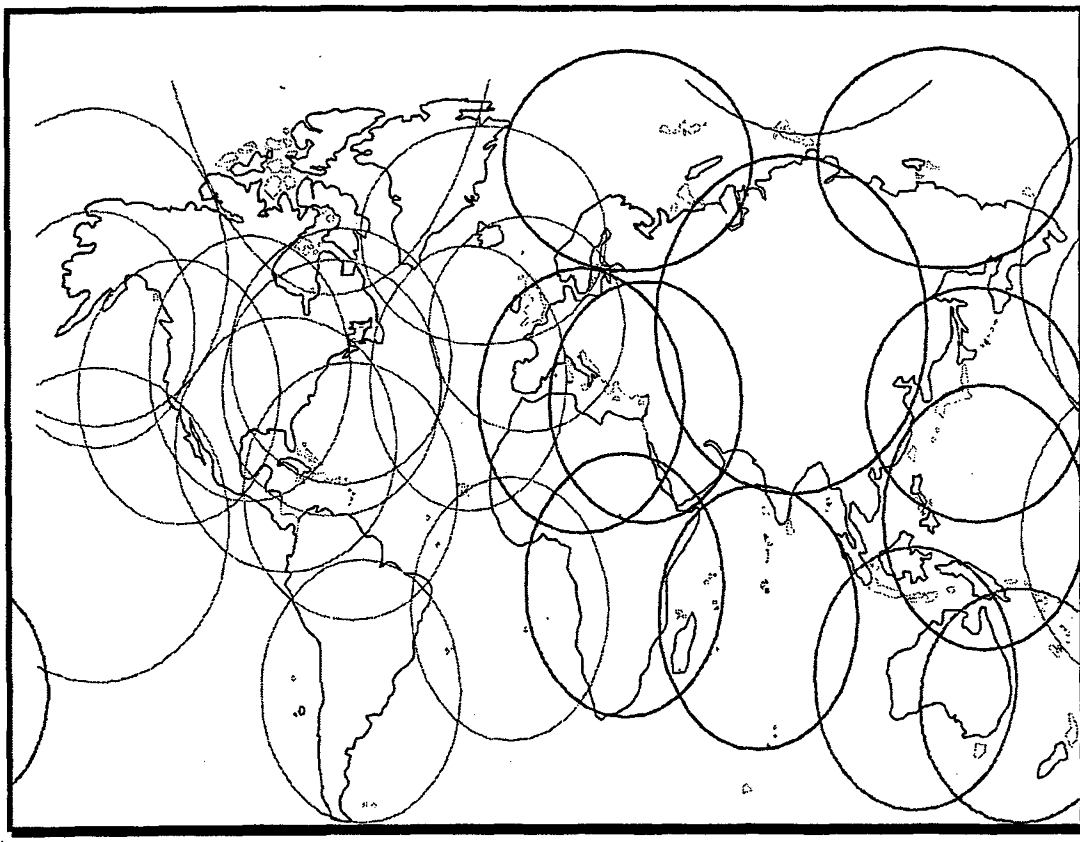

Figure 5-4. Global HF Network Coverage

StrikeStar would rely on other platforms, like Predator, DarkStar, Global Hawk or ground, airborne, or space reconnaissance, to detect and locate potential targets. The StrikeStar could team with any or a combination of all these assets to produce a lethal hunter-killer team. Once geolocated, the target coordinates would be passed to StrikeStar along with necessary arming and release data to ensure successful weapon launch when operating in command-directed mode. In autonomous mode, StrikeStar would function like current cruise missiles, but allow for in-flight retargeting, mission abort, or restrike capabilities. Communications for cooperative engagements with other reconnaissance platforms require minimum bandwidth between StrikeStar and its control station since the targeting platforms already provide the large bandwidth necessary for sensor payloads.

As with any C^4 system, we anticipate StrikeStar's requirements would grow as mission capabilities and payloads mature. It is possible StrikeStar follow-ons could be required to integrate limited sensing and strike payloads into one platform, thus significantly increasing datalink requirements. In this event, wideband laser data links could be used to provide data rates greater than 1 gigabit per second.[27] In addition, a modular payload capability could allow StrikeStar platform to carry multimission payloads such as wideband communications relay equipment to provide vital C^4 links to projected forces.[28]

Mission Control Equipment

As mentioned, StrikeStar will be controllable from a multitude of control stations through the common data link use. Control stations could be based on aerospace, ground, or sea platforms depending on the employment scenario. A control station hierarchy could be implemented depending on the employing force's composition and the number of StrikeStars under control. The StrikeStar C^2 hierarchy and control equipment would allow transfer of operator control to provide C^2 redundancy. Current efforts by DARO have established a common set of standards and design rules for ground stations.[29] This same effort needs to be accomplished for aerospace and sea based control stations.

Significant efforts to miniaturize the control stations would be needed to allow quick deployment and minimum operator support through all conflict phases. Man-machine interfaces would be optimized to present StrikeStar operators the ability to sense and feel as if they were on the platforms performing the mission. Optimally, StrikeStar control could be accomplished from a wide variety of locations ranging from mobile ground units to existing hardened facilities. The various control stations would be capable of selectively controlling StrikeStars based on apriori knowledge of platform C^2 and identification procedures.

Launch and Recovery Equipment

Launch and recovery are the most difficult UAV operations and are the greatest factors inhibiting wider acceptance.[30] A variety of launch and recovery systems are used worldwide. Launchers range from simple hand launchers to sophisticated rocket-assisted take-off systems (fig. 5-5). Recovery systems range

from controlled crash landings to standard runway landings. StrikeStar would launch and recover like manned aircraft, and carrier-based operations could be considered as another viable option to improve loiter times and mission flexibility.

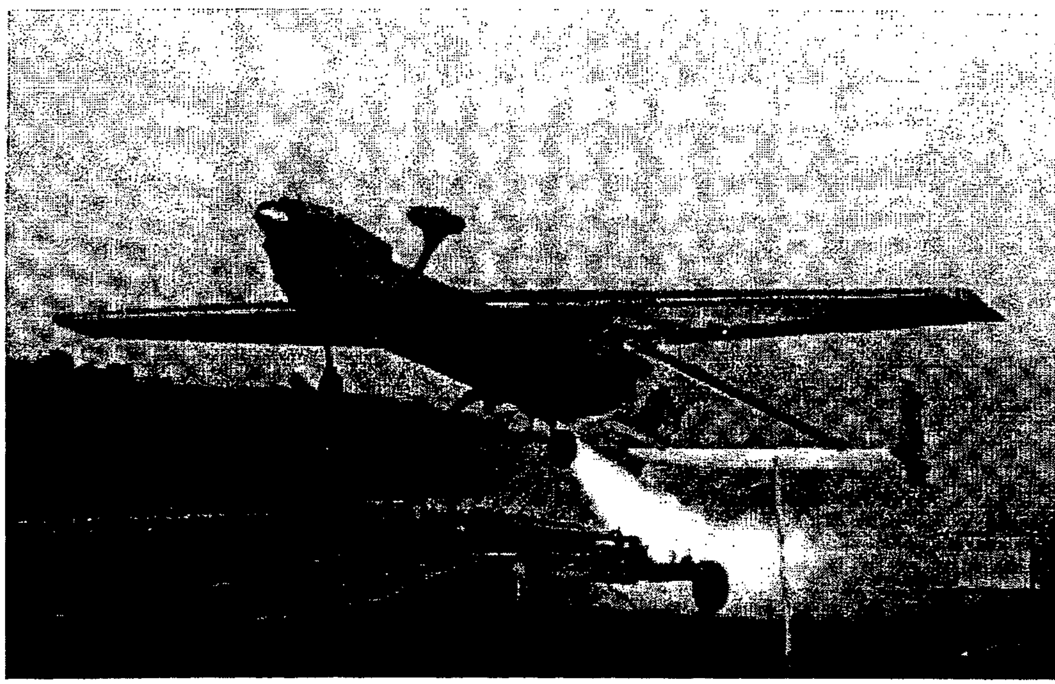

Figure 5-5. Rocket-Assisted Hunter UAV Launch

The goal for StrikeStar launch and recovery would be autonomous launch and recovery via an enhanced landing system (ELS), although it could operate with the current instrument landing system (ILS) and microwave landing system (MLS) equipment under operator control. ILS is prone to multipath propagation and MLS is susceptible to terrain variations and the presence of nearby objects; thus both would not be acceptable for truly autonomous recovery of StrikeStar platforms.[31] The ELS would overcome these deficiencies by using GPS, high resolution ground mapping techniques, and optical sensing to land without operator control.

Technologies to support the StrikeStar do not appear to represent significant challenges. In most cases proven technologies can be expected to evolve to a level that will overcome all hurdles by the year 2025. Determining the doctrinal and operational changes required to integrate a StrikeStar capability presents more significant challenges, considering the aversion our service has had with UAVs in the past.[32] Technology for StrikeStar is evolutionary where as organizational acceptance and employment will be revolutionary.

Notes

[1] Lt Col Dana A. Longino, *Role of Unmanned Aerial Vehicles in Future Armed Conflict Scenarios* (Maxwell AFB, Ala.: Air University Press, December 1994), 3–4; "Unmanned Aerial Vehicles," *Armada International*, 1990, *Naval Technical Intelligence Translation 910098*, DTIC Report AD - B153696, 10 April 1991, 3.

[2] Defense Daily, 2 February 1996, 162.

[3] Maj William R. Harshman, Army UAV Requirements and the Joint UAV Program, DTIC Report AD - A228149 (US Army Command and General Staff College Thesis, June 1990), 4.

[4] K. Cameron, *Unmanned Aerial Vehicle Technology* (Melbourne Australia: Defense Science and Technology Organization, February 1995).

[5] *Janes Unmanned Aerial Vehicles, Launchers and Control Systems, 1994* (Surrey, UK: Janes Information Group Limited), 253.

[6] Cameron, 21.

[7] *Air Progress*, September 1995, 47-49.

[8] David A. Fulghum, "McDonnell Douglas JAST Features Expanding Bays," *Aviation Week and Space Technology*, 19 February 1996, 52. In this article a smart-skin-type experimental coating is discussed. This coating attenuates radar reflections with customized carbon molecules. When activated by an electric charge it can also change the skin's color from sky blue to earth and foliage-colored hues to fool optical sensors.

[9] Ibid., 66.

[10] ARPA Technical Abstract, (Internet: December 1995).

[11] Longino, 2.

[12] Lawrence Livermore National Laboratory Technical Abstract, *Solar-Electric Aircraft* Internet: January 1996.

[13] Mr Wayne A. Donaldson, WL/POPA, Fuels Engineer, E-mail, 2 February 1996; AF 2025 Assessor comments, 28 March 1996.

[14] "Smart Bombs get their Ph.D.," *CNN Interactive Technology*, Internet, 1 February 1996.

[15] "Energetic Materials Branch/High Explosives Research and Development Facility Home Page," (Eglin AFB, Fla., January 1995).

[16] "Miniaturized Munition Technology Demonstration Abstract," January 1995, 2.

[17] Suzanne Chapman, "The Airborne Laser," *Air Force Magazine* January 1996, 54–55.

[18] E. E. Casagrande, *Nonlethal Weapons: Implications for the RAAF* (RAAF Base Fairbarin, Australia: Air Power Studies Center, November 1995), 6.

[19] Peter Petre and H. Norman Schwarzkopf, *It Doesn't Take a Hero* (N.Y.: Bantam Books, 1992), 468. Considering the death and destruction on the Highway of Death, General Powell informed General Schwarzkopf that the White House was getting nervous: "The reports make it look like wanton killing."

[20] Adm Richard C. Macke, *C4I for the Warrior*, 12 June 1992.

[21] Robert K. Ackerman, "Tactical Goals Encompass Sensors, Autonomous Arts," *Signal*, December 1995, 27.

[22] USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century*, summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), 27.

[23] Joint Precision Strike Demonstration (JPSD) Beyond Line of Sight UAV Demonstration, JPSD Program Office, March 1994, vi–viii.

[24] Adm James B. Busey IV, "MILSTAR Offers Tactical Information Dominance," *Signal*, July 1994, 11.

[25] AFC^{4}A Briefing, Global HF Consolidation, November 1994.

[26] Michael A. Wallace, "HF Radio in Southwest Asia," *IEEE Communications*, January 1992, 59-60.

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[28] Col Dale W. Meyerrose, HQ USAFE/SC, E-mail, 21 January 1996. In this E-mail Col Meyerrose explained how a long-loiter UAV capable of relaying combined air operations center communications to pilots over Bosnia would have been a much better solution than building the line-of-sight communications system in enemy territory; Kenneth L. Gainous and William P. Vaughn, *Joint Warrior Interoperability Demonstration 1995 After Action Report for the MSE Range Extension Repeater*, 16 November 1995. In this effort, a UAV was used to extend voice and data communications for US Army Deep Strike Assault Mission.

[29] Defense Airborne Reconnaissance Office Annual Report *Unmanned Aerial Vehicles*, (Washington, D.C., August 1995), 28.

[30] Cameron, 28–30.

[31] Aubrey I. Chapman, *Remotely Piloted Vehicle Technology*, DTIC AD-B131985 (Radar Guidance Inc., San Antonio, Tex., 17 April 1989), 17–18.

[32] Harshman, 17; Longino, 27–31.

Chapter 6

StrikeStar Concept of Operations

We're getting into UAVs in a big way. We understand they have enormous potential.

—General Joseph W. Ralston

The purpose of the StrikeStar concept of operations is to define the operational application of the StrikeStar by highlighting system advantages, defining future roles and missions, and illustrating interrelationships between intelligence, command and control (C^2), the weapon, and the war fighter.

The Dawn of a New Era for Airpower

Historically, America has held expectations for airpower just beyond the limits of available technology, and now a new national expectation is emerging. Today, airpower application is expected to equate to cost-effective, precise, and low-risk victory.[1] These inexorable expectations could be a reality in 2025 because a StrikeStar could hold strategic, operational, and tactical targets at risk with relative immunity to enemy defenses. This platform could operate in high risk or politically sensitive environments, perform its mission, and return to fly and fight again. The StrikeStar would enable the United States military to meet the national expectations and the threats of a changing world.

Underpinning the StrikeStar concept is the platform's ability to deliver increased combat capability with reductions in vulnerability and operating cost. The StrikeStar's 8,000 nautical mile combat radius would have the potential to keep vulnerable logistics and maintenance support far from hostile areas. Also, dramatic savings would be possible in operations, maintenance, personnel, and deployment costs.

Logistically the StrikeStar could be handled like a cruise—missile; stored in a warehouse until needed and then pulled out for a conflict. The potential savings over conventional aircraft could range from 40 percent to as much as 80 percent.[2] Training could be conducted using computer simulation with actual intelligence, surveillance, and reconnaissance inputs. While potential savings are impressive, the most attractive aspects of this platform and its supporting elements are the capabilities the StrikeStar System could deliver to tomorrow's commanders in chief (CINCs):

1. The StrikeStar could be configured to perform a variety of missions as diverse as surveillance to the delivery of precision weapons.

2. Operating altitudes could make it a true all-weather platform capable of remaining on-station regardless of area of operations (AO) weather.

3. Battlespace presence: depending on the weapons carried, a handful of StrikeStars could equate to continuous coverage of the AO.

4. Power projection: StrikeStar operations need not compete for ramp space with other theater assets. The combat radius would normally facilitate operations from coastal Continental United States locations or strategically located staging bases to improve loiter time (fig. 6-1).

5. Such an aircraft could accelerate the CINC's Observe, Orient, Decide, Act loop (OODA Loop) with immediate battle damage assessment (BDA) and restrike capability.

6. The employment concept of operations could shorten the chain of command, simplifying accountability and improving operations security.

7. A StrikeStar could enable a CINC to operate in environments where casualties, prisoners of war, or overt United State military presence are politically unacceptable.

8. A StrikeStar and its supporting systems could be tailored to have utility across the across the spectrum of conflict.

9. A StrikeStar in a combat environment could "buy back" battlespace flexibility.[3]

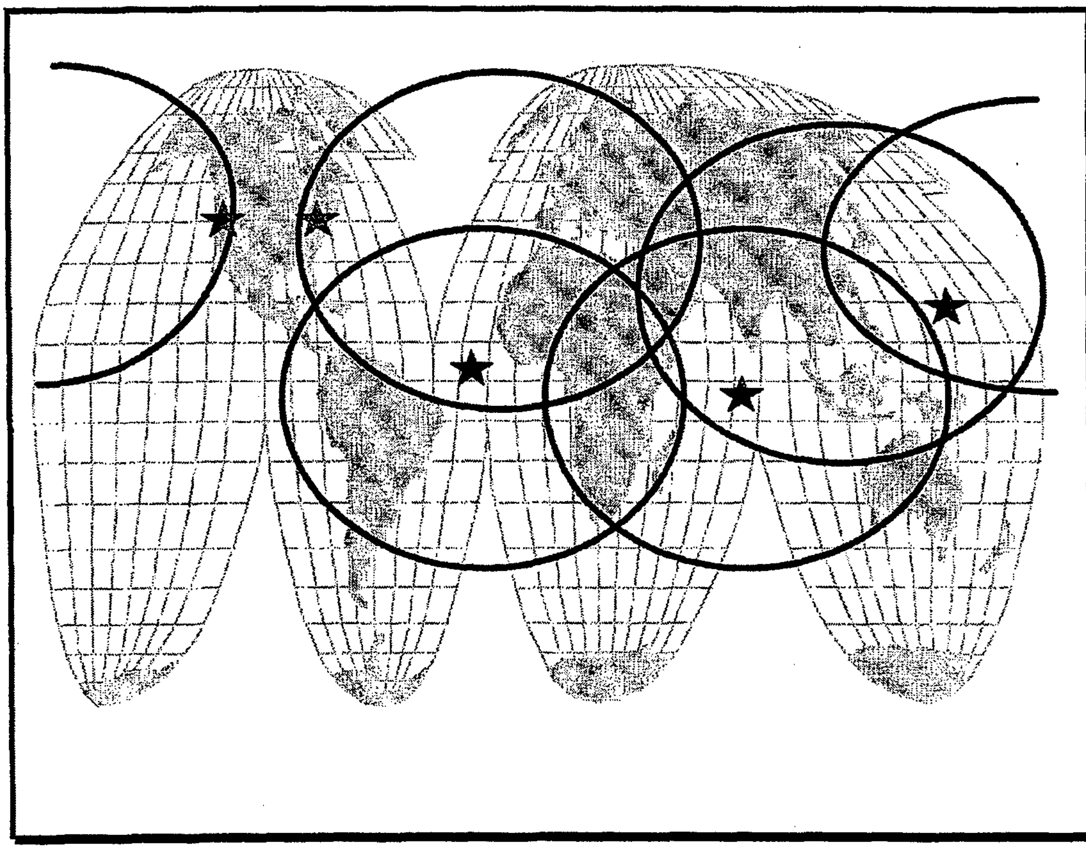

Figure 6-1. StrikeStar Coverage

Roles and Missions

Aerospacepower roles and missions in 2025 are difficult to predict, yet we know they will be tied to the nature of future conflict. Desert Storm has been touted by many as the first modern war and a clear indicator of the nature of future conflict. Others believe that the conflict was not the beginning of a new era in warfare but the end of one, perhaps the last ancient war.[4] In terms of posing aerospace forces for the future, it is imperative we look for discontinuities in the nature of future war as well as commonalties to past conflicts. It is a fact that our future roles and mission will be a reflection of our technological capabilities and most significant centers of gravity as well as those of our enemies.[5] It is safe to say the missions that are the most challenging today will be the core requirements of aerospacepower tomorrow.

The StrikeStar complements the current understanding of air roles and missions and could provide a technological bridge to accomplish future roles and missions. The platform's most natural applications would be in aerospace control and force application roles; however, planned versatility also makes it a force multiplier and a force enhancer.[6] A payload and communications package swap could enable a StrikeStar to perform electronic combat, deception, or reconnaissance missions. A StrikeStar could act as a stand-alone weapons platform or it could multiply combat effectiveness by working in conjunction with other air and space assets. StrikeStar's utility in the performing any future missions would be limited only by its combat payload capacity and this limitation will be offset by revolutions in weapons technology that include light-weight, high-explosive, and directed-energy technology.[7] Yet, even by today's standards a StrikeStar could match the planned payload capacity of the Joint Strike Fighter (JSF).[8] Revolutions in conventional warfare will be driven by rapidly developing technologies of information processing, stealth, and long-range precision strike weapons.[9] A StrikeStar's relative invulnerability, endurance, and lethality would force redefinition of roles and missions and revolutionary doctrinal innovation for airpower employment.

For centuries war fighters labored to find the weapon that gave them a panoptic effect on the battle field.[10] The inherent flexibility and lethality of airpower provided us with great gains toward this long-sought goal. However, limitations in technology, airframes, and the national purse have led to a less than ubiquitous presence over intended areas of operations. A StrikeStar could be the conduit to achieving this goal. The "kill boxes" of Desert Storm would give way to 24-hour "air occupation" of the AO. Airpower theorist Col John Warden states that the primary requirements of an air occupation platform in the future are stealth, long endurance, and precision.[11]

Not only could a StrikeStar hold the enemy at risk, it could produce unparalleled psychological effects through shock and surprise. In the words of Gen Ronald Fogleman, Chief of Staff, United States Air Force, "So, from the sky in the aerospace medium, we will be able to converge on a multitude of targets. The impact will be the classic way you win battles—with shock and surprise."[12] A StrikeStar could produce physical and psychological shock by dominating the fourth dimension—time.[13] Future CINCs could control the combat tempo at every level. Imagine the potential effect on enemies who will be unable to predict where the next blow will fall and may be powerless to defend against it.

The possibilities for joint force combat applications of this system are enormous. A StrikeStar could be a multiplier used to increase the tether of naval fleet operations or as a strike platform with marine expeditionary applications. It could be used as a high-value asset (HVA) escort or in combat air patrol (CAP), allowing assets normally tasked for these roles to be retasked for other missions. An example of a StrikeStar force enhancement capability is its potential use in tactical deception. A possible employment scenario could include a StrikeStar releasing air-launched decoys over an area of suspected surface-to-air missiles, and as enemy radars come on line to track the approaching decoys, the StrikeStar would destroy them.[14] It could then follow the strike package of F-22s or JSFs, loiter over the battle area, and perform near real-time restrike as directed.

Concepts of Employment

In this section, concepts of employment describe the architecture required to employ the StrikeStar and detail the concept of operations in two notional operating modes. The final areas covered are critical tasks and weapons employment.

The System Architecture

The StrikeStar is inextricably linked to reconnaissance and command and control systems. The system architecture depicted in figure 6-2 illustrates how a StrikeStar is tied and integrated into the larger battle space systems. Keep in mind that it is the entire architecture, or the system of systems, which enables mission accomplishment.[15] The StrikeStar is a relatively dumb system: it carries few sensors, and it is not designed for a great deal of human interface. The viability of the StrikeStar concept in 2025 depends on its ability to plug into the existing battlespace dominance and robust C^2.

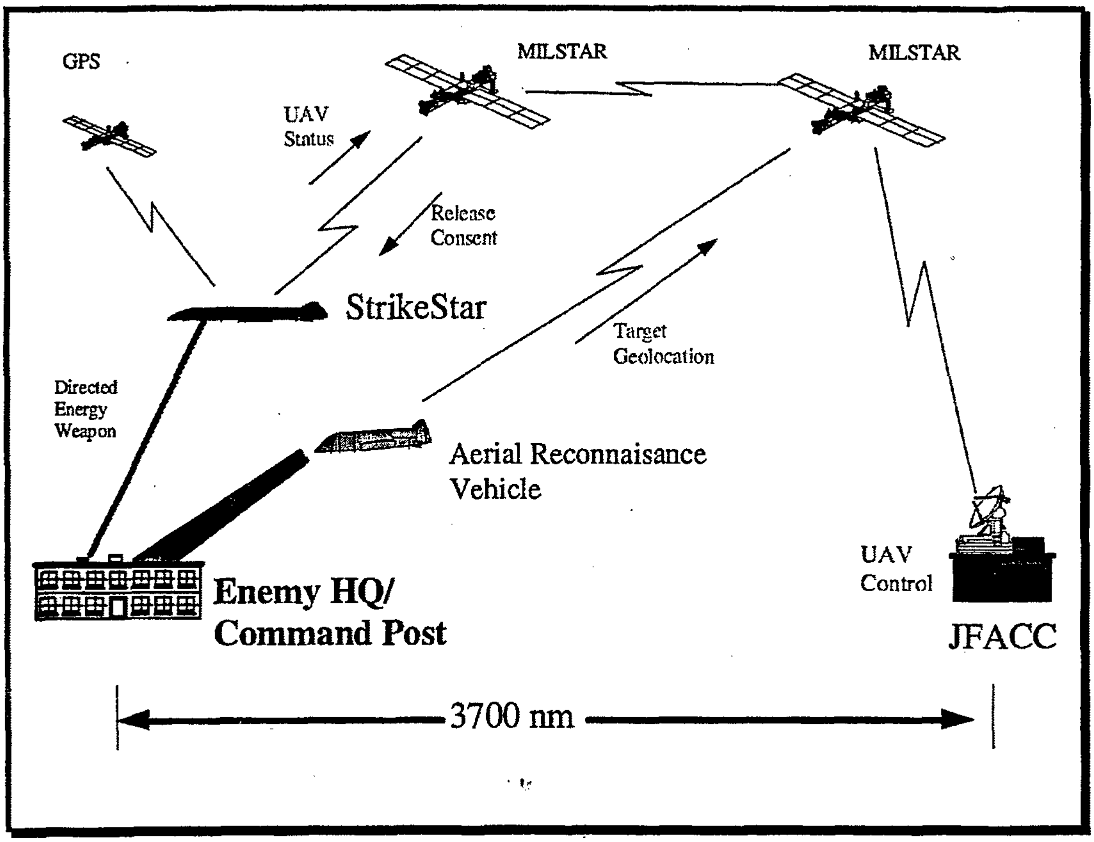

Figure 6-2. StrikeStar C^2 Architecture

Former Vice Chairman of the Joint Chiefs of Staff Admiral Owen's prediction that the United States military will enjoy dominant battlefield awareness by 2010 is a prerequisite to this concept.[16] Dominant battlespace awareness in 2025 must include near real-time situational awareness, precise knowledge of the enemy, and weapons available to affect the enemy.[17] This intelligence must be comprehensive, continuous, fused, and provide a detailed battlespace picture. The intelligence-gathering net will utilize all available inputs from aerospace assets, both manned and unmanned sensors.[18] The StrikeStar would rely on this integrated information for employment, queuing, and targeting. A StrikeStar in this architecture adds value since it enables an aerospace platform to provide dominating maneuver with lethal and precise firepower in a previously unattainable continuum of time. A pictorial representation of this concept is presented in figure 6-3.

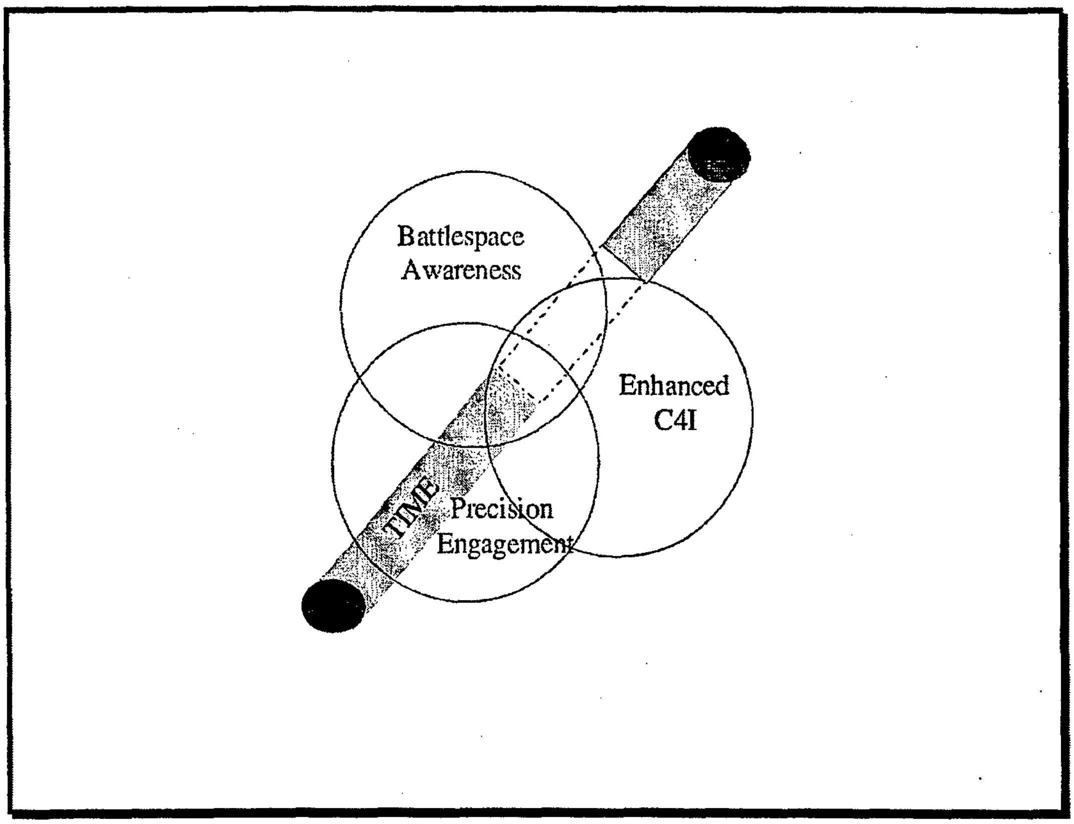

Figure 6-3. A System of Systems Over Time Continuum

Command and control capabilities in 2025 are the defining element in the StrikeStar concept. A StrikeStar would need to be fully integrated into a common C^2 element that manages all aspects of the air battle in 2025.[19] A StrikeStar places several unique demands on the command and control element. C^2 personnel would employ a StrikeStar by nominating targets, pulling down required intelligence, and selecting the platform and weapon to be used against them. The command element could then command weapons release or tie the StrikeStar directly to an AO sensor in an autonomous mode. In the autonomous mode intelligence is collected, sorted, and analyzed and then forwarded to a StrikeStar positioned to attack immediately a target by-passing the C^2 element (sensor-to-shooter).[20] To reduce vulnerability of the command center and StrikeStar, data-link emissions should be held to a minimum.

The type and location of the command center used in 2025 will depend on the nature of the conflict. Missions of the most sensitive nature, clandestine operations, or retaliatory strikes are best served by a short and secure chain of command. Therefore, these StrikeStar applications would be best served by a direct link

to the platform from a command center located in the hub of political power. Similarly, if a StrikeStar is utilized in extremely hostile theaters, a command and control center located far from hostilities is most advantageous. In low-intensity conflicts, peace enforcement, or domestic urban applications, the C^2 center could be moved to the vicinity of the conflict as a mobile ground station, an airborne platform, or even a space-based station.

Autonomous Strike Mission

The strike mission highlights the utility of a potentially autonomous mode of operation. This operating mode could free command and control center personnel to manage other assets. In the strike mode a StrikeStar would capitalize on the principles of simplicity, surprise, offensive, and objective.[21] The following details an autonomous strike mission (fig. 6-4).

Ground operations. A StrikeStar is tasked from Continental United States or a forward operating location to strike specific AO target(s). Mission specifics including target coordinates, time-on-target, takeoff time, and abort criteria are loaded directly into the aircraft computer via a physical link from the mission-planning computers. (The use of ground crew personnel is possible, however this option introduces potential for human error).

Launch. StrikeStar performs premission diagnostic checks, starts, and taxis to meet its designated takeoff time. The aircraft would require improved taxiways and runways to support a notional, maximum gross operational weight of 24,000 pounds. Taxiways and runways must provide adequate obstacle clearance to accommodate a StrikeStar's 105 feet wing span. The runway length required will be approximately 4,000 feet for takeoff, landing, and abort distances. The StrikeStar would taxi via global positioning and airfield information. Mission support personnel would deconflict operations with ground control and tower or sanitize the airfield during ground operations and takeoff.

Climb Out. When operating in congested or controlled airspace it would be necessary to deconflict a StrikeStar with potential air traffic. In these cases the aircraft would be programmed to perform a spiral climb over the field until above the future equivalent of positive controlled airspace. (This may require coordination for airspace above and around the aerodrome for operations within the United States).

Enroute. The StrikeStar would proceed to the target as programmed unless updated information is passed from the command center. Integrated engine and airframe function indicators would be constantly monitored and adjusted automatically for peak performance by the Virtual Pilot. Engine anomalies will be compared against pre-programmed go/no-go criteria, and in the event an abort criterion is discovered, a message would be automatically passed to the C^2 center for action.

Ingress. A StrikeStar would proceed to the target via the programmed flight path. Although stealthy technology and altitude reduces vulnerability, flight path programming should integrate intelligence preparation of the battlefield (IPB) to optimize this technology and avoid obvious threats. Once in the AO the StrikeStar would release its weapons or recognize its assigned sensor and establish a "kill box." The kill box is a block of space where the StrikeStar releases weapons on threats identified by coupled sensors.[22]

Egress. StrikeStar would egress the AO using preprogrammed information or remain on-station in a preprogrammed orbit awaiting battle damage assessment (BDA) and potential retargeting information until egress was required.

Recovery. StrikeStar would fly to the airdrome's vertical protected air space, and execute a spiral descent unless otherwise directed. The aircraft would perform a precision approach and landing, taxi clear of the active runway, and return to parking, using the enhanced landing system (ELS) discussed earlier.

Regeneration. Maintenance time would be kept to a minimum through computer diagnostics provided to ground personnel on landing, and blackbox swap technology. The aircraft could be refueled, rearmed, reprogrammed, and "turned" quickly after landing.

System compromise. A StrikeStar is intended to be a durable platform, however system degradation due to battle damage or malfunction could compromise the platform. To ensure that classified programming information remains secure, preprogrammed information will be altitude volatile. Additionally, to prevent reverse engineering or endangerment of friendly forces, the airframe could be destroyed by on-board weapons or another StrikeStar in the event of an inadvertent landing or errant behavior.

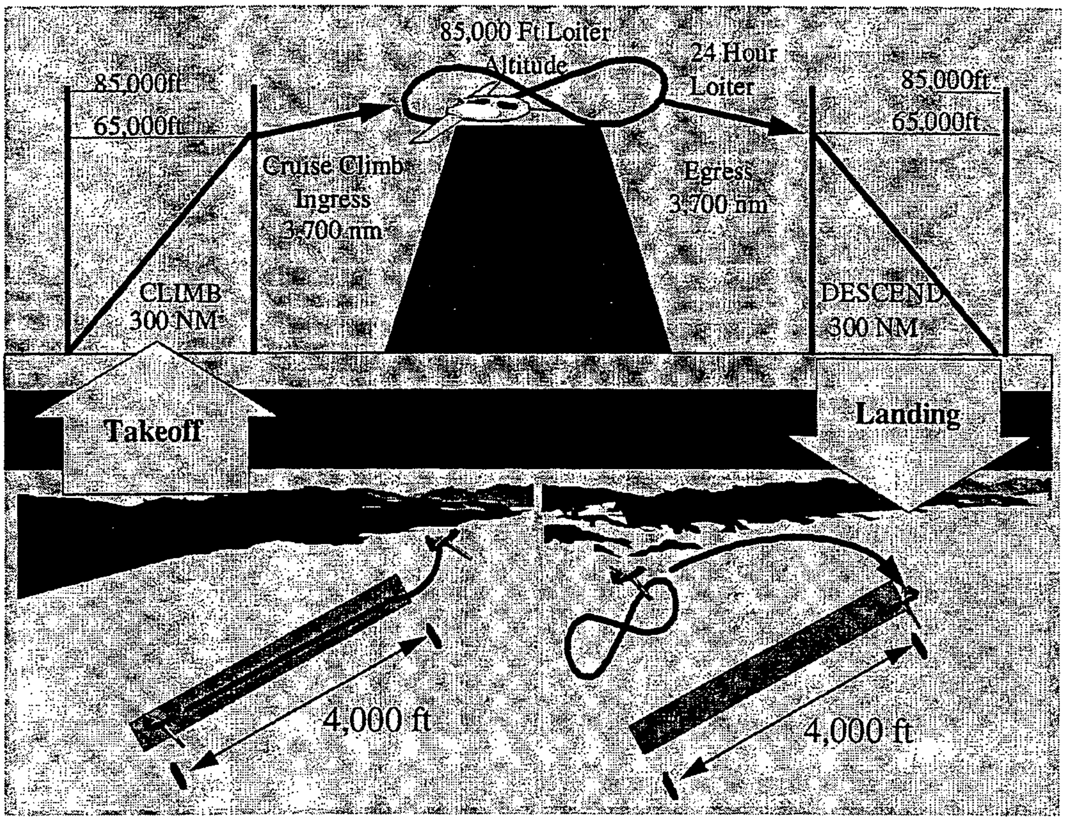

Figure 6-4. StrikeStar Mission Profile

Command Directed Mission

The specifics of the command-directed mission overlap many of the aspects of the autonomous mission. The fundamental distinction between the two operating modes is that the command directed mission requires command center inputs. In this operating mode, the StrikeStar could exploit the principles of unity of command, maneuver, mass, and economy of force. While the StrikeStar employment would naturally mesh with the tenets of aerospace power, this platform would define new limits to the tenets of persistence, flexibility, and versatility.[23] The objective of the command-directed mission is to provide continuous presence over the battle-field and maximize flexibility. Mission areas unique to command-directed missions are delineated below.

Ingress. A StrikeStar would be preprogrammed to a specific orbit where it would await closure of the C^2 elements OODA loop. This closure would provide the platform with the required information on optimum positioning and targeting commands.

Egress. A StrikeStar would remain on-station until fuel or weapons expenditures require a return to base. Fuel and weapons status will be provided to the command element on request. A return to base message will be transmitted at a predesignated navigation point. Due to the long loiter time in the AO, the planned recovery location may have changed, so updated landing information will be passed to the aircraft as situations dictate.

Critical Tasks and Weapons Employment

The 2025 battle space will have both unique and familiar features. The StrikeStar could leverage available weapons technology to perform many critical tasks. As noted in the *New World Vistas*, there will be a number of tasks that must be accomplished. Among the most pressing tasks in 2025 will be the destruction of short-dwell targets, and theater ballistic missile defense.[24] Additionally, the potential of air occupation must be explored. A final task, well suited to a StrikeStar, would be covert action against trans-national threats located in politically denied territory or in situations were plausible deniability is imperative.

The ability of a StrikeStar to loiter over an area for long periods and exploit information dominance with precision weapons, would make it a natural Theater Missile Defense (TMD) platform, particularly in boost phase intercept. A StrikeStar could be employed in the AO in a sensor-to-shooter mode looking for ballistic missiles in the first 180 seconds of flight. Intercepting missiles from high altitudes early in the boost phase increases the chances that dangerous debris would fall on enemy territory.[25] The weapon employed against TBMs or other short-dwell targets could be directed-energy weapons or hypersonic interceptor missiles.[26] The optimum weapons selection for a StrikeStar would match weapons availability to loiter capability. A StrikeStar offers the advantages of a space-based TBM defense weapon in terms of operational reach, a vast distance over which military power can be concentrated and employed decisively, and it extricates the military from the issues of the militarization of space.[27]

The StrikeStar approach to systems lethality and loiter capability could enable the Air Occupation concept. Because of a StrikeStar's endurance, altitude, and stealth characteristics, it could wait, undetected, over a specific area and eliminate targets upon receiving intelligence cues. If required for plausible deniability, specialized weapons could be used to erase any US finger-print. Uniquely suited to a StrikeStar would be delivery of high-kinetic-energy penetrating weapons. Firing kinetic weapons at StrikeStar's operational altitudes would allow engagements at longer ranges.[28]

Countries conform to the will of their enemies when the penalty of not conforming exceeds the cost of conforming. The cost can be imposed by destruction or physical occupation of enemy territory. In the past, occupation was conducted by ground forces—because there was no good substitute.[29] In 2025, a StrikeStar could send a lethal or nonlethal message to US enemies and enforce the imposition of our national will through air occupation across the battle space continuum.

It is estimated that over half the nations of the world have active UAV programs.[30] Because of the proliferation of UAV technologies, the United States may face enemy UAVs similar to StrikeStar in the future. Although beyond the scope of this paper, consideration must be given to how a StrikeStar will fit into, and possibly shape the 2025 battlespace. The broad influence that UAVs could have on military roles and missions will drive evolutionary changes in service doctrine. The issues of how best to employ strike UAVs, the details of the human-system interface, and potential countermeasures must be explored before this weapon system can fulfill its potential.

Notes

[1] USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century*, summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), 60.

[2] David A. Fulghum, "New Priorities Refocus Ballistic Missile Defense," *Aviation Week and Space Technology*, 19 February 1996, 25.

[3] Ibid., 25.

[4] Gen Merrill A. McPeak, *Selected Works 1990-1994* (Maxwell AFB, Ala.: Air University Press, August 1995), 230.

[5] Col Phillip S. Meilinger, *10 Propositions Regarding Air Power* (Maxwell AFB, Ala.: Air Force History and Museums Program, 1995), 60.

[6] AFM 1-1, *Basic Aerospace Doctrine of the United States Air Force*, 2 vols., March 1992, 7.

[7] John Boatman, "Highly Energetic Bomb Studies," *Jane's Defense Weekly,* March 1995, 81.

[8] David A. Fulghum, "Mcdonnell Douglas JAST Features Expanding Bays," *Aviation Week and Space Technology*, 19 February 1996, 52.

[9] James R. Fitzsimmonds and Jan M. Vantol, "Revolution in Military Affairs," *Joint Force Quarterly,* Spring 1994, 27.

[10] Col John Warden, USAF Retired, address to Air Command and Staff College, Maxwell AFB, Ala., October 1995. The panoptic effect refers to the power that continuous surveillance and presence has in the ability to control large numbers of people. People begin to react to the pressure of constant surveillance even when it is not present.

[11] Col John Warden, USAF Retired, video address to Air Command and Staff College, Maxwell AFB, Ala., War Termination, January 1996.

[12] Gen Ronald R. Fogleman, chief of staff, United States Air Force, address to the Air Force Association, Orlando, Fla., 24 February 1995.

[13] Col Phillip S. Meilinger, 1, 30.

[14] David A. Fulghum, "DarkStar First Flight Possible in March," *Aviation Week and Space Technology*, 19 February 1996, 55.

[15] Lt Col Michael R. Mantz, *The New Sword: A Theory of Space Combat Power* (Maxwell AFB, Ala.: Air University Press, May 1995), 17.

[16] Adm William A. Owens, USN, Vice Chairman, Joint Chiefs of Staff, address to the AF 2025 Study Group, Maxwell AFB, Ala., 13 August 1995.

[17] "Warfighting Vision: 2010 A Framework for Change," (Ft Monroe Va: Joint War fighting Center, August 1995),10.

[18] "Surveillance and Reconnaissance, Real-Time Integration," 2025 concept briefing, Maxwell AFB, Ala., 19 January 1996.

[19] Unmanned Aerial Vehicle Technology Report, 2.

[20] Warfighting Vision: 2010 A Framework for Change, 10.

[21] AFM 1-1, *Basic Aerospace Doctrine of the United States Air Force*, 7.

[22] Richard P. Hallion, *Storm over Iraq Air Power and the Gulf War* (Washington. D.C.: Smithsonian Institution Press, 1992), 155.

[23] AFM 1-1, *Basic Aerospace Doctrine of the United States Air Force*, 9.

New World Vistas, summary volume, 36.

[25] William B. Scott, "Kinetic-Kill Boost Phase Intercept Regains Favor," *Aviation Week and Space Technology*, 4 March 1996, 23.

[26] Fulghum, 53.

[27] Joint Pub 3-0 *Doctrine for Joint Operations*, 1 February 1995, III–16.

[28] William B. Scott, "Kinetic-Kill Boost Phase Intercept Regains Favor," *Aviation Week and Space Technology*, 4 March 1996, 23.

[29] Jeffrey Mckitrick et al., "The Revolution in Military Affairs," in Barry R. Schneider and Lawrence E. Grinter, eds., *Battlefield of the Future: 21st Century Warfare Issues.* (Maxwell AFB, Ala.: Air University Press, September 1995), 121.

[30]Air and Missile Threat to the Force," Air and Missile Threat Briefing, Fort Bliss Threat Office, 1996, 14.

Chapter 7

Conclusions

There will always be men eager to voice misgivings, but only he who dares to reach into the unknown will be successful. The man who has been active will be more leniently judged by the future.

—General Heinz Guderian
Armored Forces

Many important issues face our military's leadership over the next 30 years. Continuing to build a reliable force structure amidst shrinking budgets is a challenge that must be met head-on. Recognizing the opportunity for growth beyond the UAV's reconnaissance mission is a must if the US military is to be ready for all aspects of the conflict spectrum. While there are other near-term priorities for military spending, UAV development beyond reconnaissance requires specific funding for research and development, and operations and maintenance. Estimating seven years for development and three years from initial fielding to a full operational capability, the lethal UAV concept should be supported and funded no later than 2015. In reality, this milestone should be achieved earlier, but we live in an imperfect world and funding for our future force is only growing smaller.[1]

The technologies discussed here are realizable by 2025. Current UAV advanced concept technology demonstration (ACTD) efforts by Defense Airborne Reconnaissance Office's (DARO) will provide the leverage we need to take the next step in UAV missions. Current efforts to improve conventional weapons and produce an airborne-directed energy weapon will provide the required precision and lethality needed to operate across the full spectrum of conflict. An interconnected, highly distributed infosphere that produces ultimate battlespace awareness will provide the C^2 reins to provide the conventional deterrence desired.

Conventional fuel sources can provide the desired platform performance between now and 2015, but continued research to provide cleaner fuel sources and improved fuel efficiencies is desirable. StrikeStar technology is a small hurdle—a challenge that can be overcome by funding and support from visionary leaders.

UAVs have a great potential for the strategic and operational commander in the pursuit of national interests. To optimize that potential, the apparent pro-pilot bias that favors manned aircraft over UAVs must be overcome. In addition, leaders must finds ways to fund lethal UAV development and support the research and development of doctrine to support it. While doing so, leaders must also ensure that lethal UAVs and their concept of operations comply with the wishes of a public that demands safety and accountability.

Based on these conclusions, the following are recommended:

- Add a budget line in the FY00 POM, or sooner, that provides adequate funding for the ACTD. Based on the ACTD results be prepared to dedicate funding for lethal UAVs.

- Initiate an ACTD effort that picks up where the current DARO ACTDs end. The ACTD will focus on integrating components produced in the Miniaturized Munitions Technology Demonstration, LOCASS, and Pave Pace avionics architecture, with an enlarged variant of the DarkStar platform.

- Investigate a multimission modular payload configuration for UAV use that will allow a quick and economical reconfiguration from strike to reconnaissance missions.

- Continue work on an airborne laser, focusing on miniaturizing the weapon.

- Investigate possible TMD weapons for boost-phase intercept or attack operations for carriage on a long endurance stealthy UAV.

- Initiate a study to determine what doctrinal changes are needed to effectively employ StrikeStar across the conflict spectrum.

- Accelerate efforts to fuse all-source national and theater intelligence technologies.

- Initiate a study to determine how lethal UAVs can be integrated into force structure and the cost benefits of this concept versus alternatives.

- Continue strong support of a global information infrastructure that can provide secure, reliable communications.

The long-endurance multimission lethal UAV offers the war fighter of the Twenty-first century a capability to enforce the concept of "air occupation." Applicable for use over a wide variety of scenarios and levels of warfare, the StrikeStar would be an affordable power projection tool that overcomes many of the political and social issues that will hinder force projection and force employment in the next century.

Notes

[1] Maj Gen John R. Landry, USA, Retired, National Intelligence Officer for General Purpose Forces, Central Intelligence Agency, address to the AF 2025 Study Group, Maxwell AFB, Ala., 14 February 1996.

Appendix A

Unmanned Aerial Vehicle Reliability

UAV reliability constantly comes up as a major factor when conducting cost performance trade-offs between manned and unmanned aircraft. The sporadic interest in UAVs has resulted in missing reliability data or insignificant data collections due to small UAV test sets, and various measurement techniques. The propensity to link payload performance to UAV platform reliability also led to misconceptions on overall reliability.

Table 4 shows the first data collected on the Air Force's first widespread use of UAVs during the Vietnam War and its aftermath.

Table 4

Ryan Model 147 UAV Flight Statistics

RYAN 147 Model	MIL Model	LT	SP	Mission	Date Opr	Number Launch	Percent Returned	Msn Per Uav
A		27	13	Fire Fly-first recce demo	4/62-8/62			
B		27	27	Lightning Bug First Big-Wing High Alt PhotoBird	8/64-12/65	78	61.5	8
C		27	15	Trng and Low Alt Tests	10/65			
D		27	15	Electronic Intelligence	8/65	2		
E		27	27	High Alt Elect Intel	10/65-2/66	4		
F		27	27	ECM	7/66			
G		29	27	Long body/larger engines	10/65-8/67	83	54.2	11
H	AQM-34M	30	32	High Alt Photo	3/67-7/71	138	63.8	13
J		29	27	First Low Alt Day Photo	3/66-11/77	94	64.9	9
N		23	13	Expendable Decoy	3/66-6/66	9	0	
NX		23	13	Decoy and Med Alt Day Photo	11/66-6/67	13	46.2	6
NP		28	15	Interim Low Alt Day Photo	6/67-9/67	19	63.2	5
NRE		28	13	First Night Photo	5/67-9/67	7	42.9	4
NQ		23	13	Low Alt Hand Controlled	5/68-12/68	66	86.4	20
*NA/NC	AQM-34G	26	15	Chaff and ECM	8/68-9/71			
NC	AQM-34H	26	15	Leaflet Drop	7/72-12/72	29	89.7	8
NC (m1)	AQM-34J	26	15	Day Photo / Training				
S/SA		29	13	Low Alt Day Photo	12/67-5/68	90	63.3	11
SB		29	13	Improved Low Alt Day Photo	3/68-1/69	159	76.1	14
SRE	AQM-34K	29	13	Night Photo	11/68-10/69	44	72.7	9
SC	AQM-34L	29	13	Low Alt Workhorse	1/69-6/73	1651	87.2	68
SC/TV	AQM-34L/TV	29	13	SC with Real-time TV	6/72-	121	93.4	42
SD	AQM-34M	29	13	Low Alt Photo/Real-time Data	6/74-4/75	183	97.3	39
SDL	AQM-34M(L)	29	13	Loran Navigation	8/72	121	90.9	36
SK		29	15	Operation From Carrier	11/69-6/70			
T	AQM-34P	30	32	High Alt Day Photo	4/69-9/70	28	78.6	
TE	AQM-34Q	30	32	High Alt Real-time COMINT	2/70-6/73	268	91.4	34
TF	AQM-34R	30	32	Improved Long-range	2/73-6/75	216	96.8	37
						3435		

Source: William Wagner, *Lightning Bugs and Other Reconnaissance Drones* (Fallbrook, Calif.: Aero Publishers, Inc., 1982).

The percent returned varied significantly from model to model. The fact these UAVs were flying in a war zone probably accounts for many of the losses, but the inability to recover downed UAVs prevented an exhaustive analysis. Using the AQM-34L as the largest statistical data set, it is easy to assert that the percent returned represents a reliability approximation that is good, but does not meet the reliability rates seen in manned aircraft.

Data on the Pioneer UAVs shows the accident rate is still higher than manned aircraft, but some improvement is noted since 1986 as the system matured (table 5).

Table 5

Pioneer UAV Flight Statistics

Year	# Mishaps	Flight Hours	Sorties	Percent Sorties Loss	Percent Sorties Accident
1986	5	96.3	94	2.1	5.3
1987	9	447.1	279	2.5	3.2
1988	24	1050.9	577	1	4.1
1989	21	1310.5	663	1.2	3.1
1990	21	1407.9	668	<1	3.1
1991	28	2156.6	845	1.3	3.3
1992	20	1179.3	676	1	2.9
1993	8	1275.6	703	1	1.1
1994	16	1568.0	862	1	1.8
1995	16	1752/0	692	4	2.3

Source: Cmdr Davison, US Navy's Airborne Reconnaissance Office, 15 March 1996.

Data on the Hunter UAV is shown in table 6. The percentage return rate was 99.7 percent when human error is excluded and only hardware/software causes are used. The data reflects results from both early technical and user testing as well as follow-on early training for the Hunter System. There were a total of 12 strikes (UAVs damaged such that they will never return to flight) out of the total 1,207 sorties flown. Human error was assessed as the primary cause for 66 percent (8) of the 12 strikes/losses. Hardware/software was assessed as the cause for the remaining 34 percent (4) strikes. Of the 12 losses, 66 percent (8) occurred during training flights while 34 percent (4) were lost during the early technical or demonstration tests. [1]

Table 6

Early Hunter UAV Flight Statistics

Date of Operations	Number of Sorties	Percent Returned	Average Flight Duration
1/1/91-2/20/96	1207	99.0	2.97 flight hours

The latest Predator UAV data is shown in table 7. The Predator has been supporting reconnaissance missions in Bosnia and two UAVs have been lost: one to ground fire (Predator 8) and one to an engine malfunction (Predator 1). Used for training now, the GNAT-750 was originally developed for the Central Intelligence Agency and was also used in Bosnia.

Table 7

Predator UAV Flight Statistics

Model	Date OPR	Total Flights	Total Flight Hours	Bosnia Flights	Bosnia Flight Hrs	Percent Returned
GNAT-750	9/94 - 2/96	73	161			100
Predator 1	6/94 - 8/95	74	328	10	60	94
Predator 2	9/94 - 8/95	87	452	23	145	100
Predator 3	11/94 - 10/95	50	205	29	128	100
Predator 4	9/95 - 2/96	47	132			100
Predator 5	2/95 - 11/95	99	301			100
Predator 6	3/95 - 2/96	28	90			100
Predator 7	5/95 - 2/96	18	42			100
Predator 8	7/95 - 8/95	11	41	4	20	92
Predator 9	8/95 - 2/96	74	476	49	371	100
Predator 10	8/95 - 10/95	19	147	15	127	100
		580	2375	140	851	

Source: Manny Garrido, Director of Advanced Airborne Systems, Battlespace Inc., Arlington, Va., 22 February 1996.

[1] Mr Bill Parr, US Army Joint UAV Office, Redstone Arsenal, Ala., provided the Hunter data and crash data on 2 April 1996.

Appendix B

Worldwide Unmanned Aerial Vehicles

Steven J. Zaloga's article "Unmanned Aerial Vehicles" in the 8 January 1996 issue of Aviation Week and Space Technology provides a comprehensive listing of ongoing efforts in UAV production (table 8). Thirty-four companies, including 16 US companies, are represented here. Nine countries besides the United States are involved in UAV design and production. Included in this group are many peer competitors or nations involved in arms exports.

Table 8

Worldwide UAV Systems

Manufacturer	Type	Mission	Weight	Payload	Speed	Endurance	Max. Alt
AAI							
Hunt Valley, MD, USA	Shadow 200	Multimission	250	Various	100+	3+ hr.	15,000
	Shadow 600	Multimission	600	Various	100+	12+ hr.	17,000
Adv Tech & Engr. Co.							
(Pty) Ltd., South Africa	UAOS	Multimission	275	Optronic Day Sight	100	3 hr.	16,400
Aero Tech							
of Australia Pty, Ltd.	Jindivik Mk. 4A	Target	4,000	—	M 0.86	115 min.	—
Aerovironment Inc.							
Simi Valley, CA, USA	C. 22	Target	1,210	Radio cmd (R/c)	M 0.95	2.5 hr.	—
	HILINE	HALE Recce	770	Autop. datalink,	120	1-2 days	40,000
				nav. computer			
	Pathfinder	HALE Recce	480	Comm. relay,	—	—	75,000
				environ. sensing			
	Pointer	Multipurpose/Recce	8 lb.	R/c	25-50	2 hr.	2,000
	SASS-LITE	Multimission	800 lb.	Autop.	27	4 hr.	5,000

Manufacturer	Type	Mission	Weight	Payload	Speed	Endurance	Max. Alt
Aurora Flight Systems							
Manassas, VA, USA	Chiron	Marine Science	4,630	Scientific	100	24 hr.	10,560
	Perseus A	Atmo. Science	1,750	Atmospheric	80	5 hr.	74,000
				sampling			
	Perseus B	Atmo. Science	2,500	Atmospheric	80	36 hr.	63,000
				sampling			
	Theseus	Atmo. Science	8,800	Scientific	50	48 hr.	90,000
CAC Systems							
Vendomõise, France	ECLIPSE T1	Target	300	IR & RF equip.	M 2.5	ballistic	42,000
	ECLIPSE T2	Target	450	IR & RF equip.	M 4.3	ballistic	70 mi.
	FOX AT1/AT2	Recce/surv.	160/250	R/c, program., track.	160	22 hr./5hr.	10,500
	FOX TS1	Target	160	Autop., GPS	190	1 hr.	10,500
	FOX TS3	Target	240	Autop., Nav., GPS	280	1 hr.	15,800
	FOX TX	Electronic warfare	250	Autop., Nav., GPS	160	5 hr.	10,500
Canadair, Bombardier Inc.							
Montreal, Quebec, Canada	AN/USD-501	Surv./target acq.	238	Programmed	460	75 nm.	—
	AN/USD-502	Surv./target acq.	—	Programmable	—	—	—
	AN/USD-502	Surv./target acq.	—	Programmed	—	—	—
	CL-227	Surv./target acq.	502	R/c, prog.	92	4 hr.	—
	CL 289	Recce and surv.	529	Optical camera,	460	1,242 mi.	1,970
		target acquisition					
Daimler-Benz Aerospace							
Dornier, Germany	DAR	Antiradar	264.5	Pass. radar seeker	155	3 hr.	9,840
	Seamos	Maritme surv.	2,337	Radar, EO	103	4.5 hr.	13,125
	SIVA	Recce, surv.,	441	Flir, CCD, TV	92	8 hr.	8,200
		target acq.					
Flight Refueling Ltd.							
Winborne, Dorset, UK	Raven	Surv./Recce	185	Video, Flir	75	3 hr.+.	14,000
Freewing Aerial Robotics							
College Park, MD, USA	Scorpion 60	Multipurpose	110	Various 25 lb.	100	3-4 hr.	5,000
	Scorpion 100	Multipurpose	320	Flir, EO, 50 lb.	172	4 hr.	15,000
General Atomics							
San Diego, CA, USA	BQM-34A	Target	2,500	R/c	690	692 nm.	—
	J/AMQ-2	Target	519	R/c	M 0.9	15.6 min	—
	Altus	High alt.-research	1,600	—	130	48 hr.	50,000
	GNAT 750	Recce/surv./target	1,126	Day TV, Flir	150 kt.	40 hr.	25,000
	I-GNAT	Recce/surv./target	1,140	Day TV, Flir	175 kt.	60 hr.	32,000
	Predator	Recce/surv./target	2,085	Day TV Flir, SAR	120 kt.	60 hr.	25,000
	Prowler-CR	Recce/surv./target	200	Day TV, Flir	160 kt.	8 hr.+	20,000
Honeywell, Defense							
Avionics Systems Div	QF-104J	Target	23,690	—	M2.2	—	—
Albuquerque, NM, USA	QF-106	Target	35,411	—	M2.2	—	—
	QR-55	Target	7,000	—	133	—	—
Israel Aircraft Industries,							
Malat Div. Tel Aviv, Israel	Eyeview	Recce, surv.,	174	Varies	120 kt.	4-6 hr.	10,000
		& target acq.					
	Helistar	OTH target acq.,	2,450	computer	100 kt.	4.5 hr.	—
		Recce, & surv.					
	Heron	Multipurpose	2,400	—	125	52 hr.	32,000
	Hunter	Recce/surv.	1,600	—	110	12 hr.	15,000
	Pioneer	Recce/surv.	430	Computer	90 kt.	6.5 hr.	—
	Searcher	Recce/surv.	700	Computer	110 kt.	24 hr.	—

Manufacturer	Type	Mission	Weight	Payload	Speed	Endurance	Max. Alt
Kaman Aerospace Int.Corp.							
Bloomfield, CT, USA	QUH-1B,C,E,M	Target	9,500	Radar command	126	155 min.	—
				Digital control			
Kamov Design Bureau							
Moscow, Russian Fdr	Ka-37	Recce, comm.	550	Preprog or r/c	59 kt.	4.5 min.	5,200
Lear Astronautics Corp.							
Santa Monica, CA, USA	Skyeye R4E-50	Multipurpose	780	125	8+ hr.	15,000+	—
Lockheed Martin Skunk							
Works Palmdale, CA, USA	Dark Star	Acq./Recce/surv.	8,600	SAR	288+	8+ hr.	45,000+
Lockheed Martin							
Electronics & Missiles	AQM-127A	Target, SLAT	2,400	Inertial, radar	M 2.5	55 nm.	—
Orlando, FL, USA		(Super Sonic Low)					
Meteor Acft & Electronics							
Rome, Italy	Mirach 20	Surv./target/acq.	374	R/c, prog.	120	240+	—
	Mirach 26	Surv./target/acq.	440	R/c, prog.	135	420+	—
	Mirach-70	Target	525	R/c	195	60	—
	Mirach-100/4	Target	594	R/c, prog.	M 0.8	60	—
	Mirach-150	Recce	748	R/c, prog.	M 0.7	80	—
Mission Technologies							
Hondo, TS, USA	Hellfox	Multimission	240	Flir, TV, other	80 kt.	4 hr.	15,000+
Northrop Grumman Corp.							
Los Angeles, CA, USA	BQM-74E	Target	595	R/c	530 kt.	—	—
People's Rep of China							
	B-2	Target	123.5	R/c	149	1 hr.	—
	Changkong IC	Target	5,401	R/c	565	45 min.	—
	D-4	Target	308	R/c	106	2.6 hr.	—
Raytheon Acft Co., (Beech)							
Wichita, KS, USA	AQM-37	Target Variant	620	Radio cmd./prog.	M 4.0	120 nm.	—
	AQM-37A	Target	560	Programmed	M 0.7-2	120 nm.	—
	AQM-37C	Target	581	Radio cmd./prog.	M 1.0-3	120 nm.	—
	AQM-37EP	Target	600	Radio cmd	M 3.0-4	120 nm.	—
				preprog. autopilot			
	MQM-107B/D	Target	977/1012	Radio cmd./prog.	M 0.80	90m/100m	—
	MQM-107D	Target	977/1012	Radio cmd./prog.	M 0.80	100 min.	—
	Upgrade						
	MQM-107E	Target	977/1012	Radio cmd./prog.	M 0.85	100 min.	—
SAGEM							
Paris, France	Crecerelle	Recce/surv./target	265	Flir, EW	155	5 hr.	15,000
	Marula	Recce/surv./target	165	Flir, EW	155	5 hr.	15,000
Scaled Composites							
Mojave, CA, USA	Raptor 2	Environ. research	2000	Environt. sensors	92	10 hr.	65,000
Sikorsky							
Stratford, CT, USA	Cypher	Recce	250	EO, Flir, etc.	60	3 hr./2,500	7,900
Silver Arrow							
Rishon-Lezion, Israel	Colibri	Pilot training	50	—	31-100	2 hr.	10,000
	Hermes 450	Multipurpose	1000	Various up to 350 lb.	57-115	25 hr.	23,000
	Micro-Vee	Tactical UAV	100	Video camera	50-126	5 hr.	15,000
STN Atlas Electronik							
Bremen, Germany	Brevel	Recce/surv./target	330	Thermal Imaging	136	5.5 hr.	11,500
				camera			
	Luna	Optical Recce	44	TV, Flir	124	2 hr.	3,300
	Tucan-95	Recce/surv./target	330	TV, Flir	155	10 hr.	13,100

Manufacturer	Type	Mission	Weight	Payload	Speed	Endurance	Max. Alt
Strela Production Assn.							
Orenberg, Russian Fed	La-17MM	Target	5,070	Transponder	560	1 hr.	—
	La-17R	Recce	6,835	Camera	560	1 hr.	—
	Dan	Target	760	Transponder	440	40 min.	—
Tadiran Israel Electronic,							
Industries Ltd., Israel	Mastiff Mk. 3	Recce/surv.	254	R/c; prog.	100	7+ hr.	—
		& target acq.					
Target Technology Brux,							
France & Ashford, UK	Banshee 1	—	190	Flares	54-200	1.5 hr.	23,000
	Banshee 2	—	190	Flares	57-236	1.5 hr.	23,000
	IMP	Operator Training	—	—	15-90	0.5 hr.	—
	Petrel	Ballistic Target	—	—	M 3.0	104 mi.	—
	Snipe Mk 5	Aerial Target	145	Flares	180	1.2 hr.	18,000
	Snipe Mk 15	Aerial Target	—	Flares	130	0.5 hr.	5,000
	Spectre	Surveillance, EW	—	CCD camera	77-150	3-6 hr.	23,000
Teledyne Ryan Aero.							
San Diego, CA, USA	324	Recce	2,374	Program command	M 0.80	1,400 nm.	—
	Teledyne 410	Recce/surv.	1,800	Program command	169 kt.	14 hr@10K	—
	BQM-34A	Target	2,500	RPV Trk Cntrl Sys.	M 0.97	692 nm.	—
	BQM-34S	Target	2,500	Integ. Trk Cntrl Sys.	M 0.97	692 nm.	—
	MQM-34D	Target	2,500	DTCS	M 0.97	692 nm.	—
	BQM-145A	Recce	2,000	Programmable	M 0.91	700 nm.	—
	Tier 2+	Recce	24,000	—	395	42hr	67,300
	YBQM-145A	Recce	2,000	Program command	M 0.91	700 nm.	—
Tupolev Design Bureau							
Moscow Russian Fed	DBR-1 Jastreb	Recce	84,875	Camera or Elint	1,740	1.5 hr.	—
	VR-2 Strizh	Recce	15,400	Camera	685	1 hr.	—
	VR-3 Reys-D	Recce	3,110	Camera or TV	595	15 min.	—
Westinghouse Electronic							
Huntsville, AL, USA	Star-Bird	Recce, surv.,	280	Flir, TV	—	6.5 hr.	—
		C101& target acq.					
Yakolev Design Bureau							
Moscow Russian Fed	Shmel	Surv., EW	286	R/c uplink	97 kt	2 hr.	9,850
	Yak-060	Recce, EW	225	TV or EW jammer	110	2 hr.	—
	Yak-061	Recce	285	TV	110	2 hr.	—

Source: Tim H. Storey, Director of Operations, Teal Group Corporation, Fairfax Va.

Appendix C

Contributors

Lt Col (Colonel select) Bruce W. Carmichael is a command pilot with more than 4,300 flying hours in T-37, T-38, B-52, and U-2 aircraft. He has a Bachelor of Arts degree in government from Colby College and a Masters in Public Administration degree from Golden Gate University. He is a distinguished graduate of Squadron Officer School and received a National Defense University award as a student at Armed Forces Staff College. Lieutenant Colonel Carmichael is a 1996 graduate of the Air War College. He has commanded the 99th Reconnaissance Squadron (U-2 aircraft) and served on the staff of the United States Pacific Command and on the staff of the Office of the Secretary of Defense in the Defense Airborne Reconnaissance Office.

Maj Troy E. DeVine is a senior pilot with more than 3,000 flying hours in the T-37, T-38, and U-2. She is a United States Air Force Academy graduate with a Bachelor of Science degree in engineering mechanics. Major DeVine is a distinguished graduate of Squadron Officer School and is a 1996 graduate of Air Command and Staff College. She has served as the director of combat operations in the 99th Reconnaissance Squadron (U-2 aircraft) and will be attending the School of Advanced Air Power Studies next year.

Maj Robert J. Kaufman. Major Kaufman received his USAF commission through ROTC upon graduating Clemson University in 1982 with a degree in electrical engineering. He received a Master of Systems Analysis degree from University of West Florida in 1984 and completed postgraduate work in electrical engineering in 1992 at University of Colorado at Colorado Springs. He has served in a variety of positions to include: electronics engineer and program manager at the USAF Armament Laboratory, section chief and commander of an operational test and evaluation detachment, and USAF Academy instructor and coach. Prior to attending ACSC, he served a tour at Headquarters USAFE where he was a branch chief in the MAJCOM's Computer Systems Field Operating Agency and executive officer for the Directorate of Command, Control, Communications, and Computers. Upon graduating from ACSC, he will be assigned as commander, 509th Communications Squadron, Whiteman AFB, Missouri.

Maj Patrick E. Pence. Major Pence graduated from the United States Air Force Academy in 1983 with a degree in electrical engineering. He also holds a Master in systems management degree (1988) from Troy State University in Alabama. After attending pilot training at Laughlin AFB, Texas, Major Pence completed initial F-4 training at Homestead AFB, Florida, and flew the F-4E operationally at Taegu AB, Korea, and Moody AFB, Georgia. After Wild Weasel training at George AFB, California, in 1988, Major Pence flew the F-4G operationally at Clark AB, Philippines; Spangdahlem AB, Germany; and Nellis AFB, Nevada. He flew 37 combat missions in Operation Desert Storm and has flown 118 combat missions in support of Operations Southern Watch, Provide Comfort, and Vigilant Warrior no-fly zones. During this time he served as chief of scheduling and flight commander 81st Fighter Squadron, and as chief of weapons and flight commander 561st Fighter Squadron.

Maj Richard S. Wilcox Major Wilcox earned a Bachelor of Science in computer information systems from Arizona State University in 1983. He is a senior pilot with more than 1,500 hours of fighter time in F-111A, D, E, and F aircraft. Major Wilcox is a distinguished graduate from Air Force ROTC, undergraduate navigator training, undergraduate pilot training, and Squadron Officers School. His assignments have included mission-ready flying duties at Royal Air Force Upper Heyford, United Kingdom and Cannon Air Force Base, New Mexico, where he held every qualification available to an F-111 pilot. As a member of Cannon's 524th Fighter Squadron, Major Wilcox flew 19 combat sorties in support of Operation Provide Comfort II. His last assignment was advisor to the 27th Operations group commander in development of Quality Air Force initiatives for six fighter squadrons and two base-hosted detachments.

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NAVAL POSTGRADUATE SCHOOL
MONTEREY CA

(U) Integration of a Multi-Rate Position Filter in the Navigation System of an Unmanned Aerial Vehicle (UAV) for Precise Navigation in the Local Tangent Plane (LTP)

DESCRIPTIVE NOTE: Master's thesis
MAR 1998 74 PAGES
PERSONAL AUTHORS: Perry, Robert C.

UNCLASSIFIED REPORT

ABSTRACT: (U) Differential global positioning system (DGPS) provides highly accurate position information, but at update rates of one HZ which is inadequate for precise aircraft terminal maneuvering such as take off and landing. During this period between updates an accurate position estimate in Local Tangent Plane (LTP) can be made using complementary filtering of the DGPS position and indicated airspeed. Use of indicated airspeed as the filter velocity input necessitates the transformation from body to inertial (LTP) reference frame using Euler Angle Information available from the Inertial Measuring Unit (IMU) or DGPS. This filter provides accurate estimates of both vehicle position and existing wind. These filter outputs of position and wind can then be used as inputs to a trajectory controller to ultimately enable autonomous launch and recovery of an Unmanned Aerial Vehicle.

DESCRIPTORS: (U) *GLOBAL POSITIONING SYSTEM, *REMOTELY PILOTED VEHICLES, *INERTIAL MEASUREMENT UNITS, FLIGHT TESTING, THESES, AIR NAVIGATION, AIRSPEED, AUTONOMOUS NAVIGATION, INERTIAL NAVIGATION, EULER ANGLES.

AD-A345061/JAA

NAVAL POSTGRADUATE SCHOOL
MONTEREY CA

(U) Applications of Rapid Prototyping to the Design and Testing of UAV Flight Control Systems

DESCRIPTIVE NOTE: Master's thesis
MAR 1998 108 PAGES
PERSONAL AUTHORS: Komlosy, John A.

UNCLASSIFIED REPORT

ABSTRACT: (U) The modern engineer has a myriad of new tools to assist in the design and implementation of ever increasingly complex control systems. A promising emerging technology is rapid prototyping. By totally integrating the development process, a Rapid Prototyping System (RPS) takes the designer from initial concept to testing on actual hardware in a systematic, logical sequence. At the Naval Postgraduate School (NPS), we have applied the concept of rapid prototyping to the discipline of flight control. The NPS RPS consists of a commercially available rapid prototyping software suite and open architecture hardware to permit the greatest possible range of control and navigation projects. The RPS is crucial in that it allows students to participate in projects from the initial concept to the flight testing phase of the design process. This thesis will describe in detail two of these projects; the development of an Airspeed Controller using the RPS tools; and the integration of a voice control system developed By VIA, Inc. of Northfield, Minnesota. Both projects demonstrate the inherent flexibility and risk reduction of the rapid prototyping approach to system design.

DESCRIPTORS: (U) *FLIGHT CONTROL SYSTEMS, *DRONES, COMPUTER PROGRAMS, FLIGHT TESTING, RISK, THESES, REDUCTION, NAVIGATION, AIRSPEED, RANGE(DISTANCE), VOICE COMMUNICATIONS.

AD-A344726/JAA

NAVAL POSTGRADUATE SCHOOL
MONTEREY CA

(U) Design of Digital Control Algorithms for Unmanned Air Vehicles

DESCRIPTIVE NOTE: Master's thesis
MAR 1998 100 PAGES
PERSONAL AUTHORS: Froncillo, Steven J.

UNCLASSIFIED REPORT

ABSTRACT: (U) Recent advances in the design of high performance aircraft, such as fly by wire controls, complex autopilot systems, and unstable platforms for greater maneuverability, are all possible due to the use of digital control systems. With the aid of modem control tools and techniques based on state-space methods, the aerospace engineer has the ability to design a dynamic aircraft model, verify its accuracy, and design and implement the controller within a matter of a few months. This work examines the digital control design process utilizing a rapid prototyping system developed at the Naval Postgraduate School. The entire design process is presented, from design of the controller to implementation and flight test on an Unmanned Air Vehicle (UAV).

DESCRIPTORS: (U) *AIRCRAFT MODELS, *REMOTELY PILOTED VEHICLES, *AIRCRAFT DESIGN, ALGORITHMS, FLIGHT TESTING, DIGITAL SYSTEMS, MANEUVERABILITY, CONTROL SYSTEMS, HIGH RATE, AIRCRAFT, TOOLS, PERFORMANCE(ENGINEERING), DYNAMICS, ACCURACY, AEROSPACE SYSTEMS, PLATFORMS, UNMANNED, ENGINEERS, MODEMS, AUTOMATIC PILOTS.

IDENTIFIERS: (U) *RAPID PROTOTYPES, UAV (UNMANNED AIR VEHICLES).

AD-A342293/JAA

AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB, OH
SCHOOL OF ENGINEERING

(U) Embedding a Reactive Tabu Search Heuristic in Unmanned Aerial Vehicle Simulations.

DESCRIPTIVE NOTE: Master's thesis,
MAR 1998 260 PAGES
PERSONAL AUTHORS: Ryan, Joel L.

UNCLASSIFIED REPORT

ABSTRACT: (U) We apply a Reactive Tabu Search (RTS) heuristic within a discrete event simulation to solve routing problems for Unmanned Aerial Vehicles (UAVS). Our formulation represents this problem as a Multiple Traveling Salesman Problem with time windows (MTSPTW), with the objective of attaining a specified level of target coverage using a minimum number of vehicles. Incorporating weather and probability of UAV survival at each target as random inputs, the RTS heuristic in the simulation searches for the best solution in each realization of the problem scenario in order to identify those routes that are robust to variations in weather, threat, or target service times. Generalizing this approach as embedded Optimization (EO), we define EO as a characteristic of a discrete event simulation model that contains optimization or heuristic procedures that can affect the state of the system. The RTS algorithm in the UAV simulation demonstrates the utility of EO by determining the necessary fleet size for an operationally representative scenario. From our observation of robust routes, we suggest a methodology for using robust tours as initial solutions in subsequent replications. We present an object oriented implementation of this approach using MODSIM III, and show how mapping object inheritance to the GVRP hierarchy allows for minimal adjustments from previously written objects when creating new types. Finally, we use EO to conduct an analysis of fleet size requirements within an operationally representative scenario.

DESCRIPTORS: (U) *COMPUTERIZED SIMULATION, *TARGET ACQUISITION, *REMOTELY PILOTED VEHICLES, ALGORITHMS, MULTIPLE TARGETS, THESES, MONTE CARLO METHOD, HEURISTIC METHODS, OBJECT ORIENTED PROGRAMMING.

IDENTIFIERS: (U) RTS(REACTIVE TABU SEARCH), TRAVELING SALESMAN PROBLEMS

AD-A341256/JAA

HUMAN FACTORS RESEARCH INST TNO SOESTERBERG (NETHERLANDS)

(U) Remotely Controlled Flying Aided by a Head-Slaved Camera and HMD.

DESCRIPTIVE NOTE: Final report,
8 DEC 1997 23 PAGES
PERSONAL AUTHORS: De Vries, S. C.; Padmos, P.

UNCLASSIFIED REPORT

ABSTRACT: (U) Military use of Unmanned Aerial Vehicles (UAVs) is gaining importance. Video cameras in these devices are often operated with joysticks and their image is displayed on a CRT. In this experiment, the simulated camera of a simulated UAV was slaved to the operator's head movements and displayed using a helmet mounted display (HMD). The task involved maneuvering a UAV along a winding course marked by trees. The influence of several parameters of the set up (HMD Optics, Field Of View (FOV), Image Lag, Monocular vs. Stereoscopic Presentation) on a set of flight handling characteristics was assessed. To enable variation of FOV and to study the effect of the HMD optics, a simulated HMD image consisting of a head slaved window (with variable FOV), was projected on a screen. One of the FOVs, generated in this way, corresponded with the FOV of the real HMD, enabling a comparison. The results show that the simulated HMD yields a significantly better performance than the real HMD. Performance with a FOV of 17 deg is significantly lower than with 34 or 57 deg. An image lag of 50 ms, typical of pan and tilt servo motor systems, has a small but significant influence on steering accuracy. Monocular and Stereoscopic presentation did not result in significant performance differences.

DESCRIPTORS: (U) *UNMANNED, *CAMERAS, *REMOTE CONTROL, *HELMET MOUNTED DISPLAYS, SIMULATION, OPTICS, MANEUVERABILITY, STEERING, AIRCRAFT, NETHERLANDS, ACCURACY, FLIGHT, IMAGES, AERODYNAMIC CHARACTERISTICS, HANDLING, DUTCH LANGUAGE, CATHODE RAY TUBES, TELEVISION CAMERAS, SERVOMOTORS.

IDENTIFIERS: (U) FOREIGN REPORTS, UAVS(UNMANNED AERIAL VEHICLES), HMD(HELMET MOUNTED DISPLAY).

AD-A340948/JAA

NEW MEXICO STATE UNIV LAS CRUCES COMPUTING RESEARCH LAB

(U) Facility for Cognitive Engineering Research on Team Tasks (CERTT)

DESCRIPTIVE NOTE: Final report. 1 APR-31 DEC 97
31 MAR 1998 15 PAGES
PERSONAL AUTHORS: Cooke, Nancy J.; Shope, Steven M.

UNCLASSIFIED REPORT

ABSTRACT: (U) This document describes the equipment purchased under The Defense University Research Instrumentation Program awarded in 1997 to Nancy J. Cooke of the Psychology Department of New Mexico State University. The equipment is housed in the CERTT (Cognitive Research on Team Tasks) Laboratory of the Psychology Department. This laboratory is dedicated to research on team cognition and the development and evaluation of measures to support this research. The equipment consists of four interconnected participant workstations and an experimenter workstation, as well as a head tracker and network connections. Each workstation contains two computers and monitors, a video monitor, a communications module, and a video camera. Together, this equipment and associated software provide a platform for a variety of synthetic team tasks and support experimental control, data collection, and data analysis functions. The first synthetic task to be developed using this platform captures the cognitive requirements of a UAV (Unmanned Air Vehicle) task.

DESCRIPTORS: (U) *COGNITION, *WORKPLACE LAYOUT, *PSYCHOLOGICAL LABORATORIES, COMPUTERIZED SIMULATION, WORK STATIONS, COMPUTER NETWORKS, MAN MACHINE SYSTEMS, RESEARCH MANAGEMENT, REMOTELY PILOTED VEHICLES, EXPERIMENTAL PSYCHOLOGY.

AD-A339474/JAA

NAVAL RESEARCH LAB WASHINGTON DC
OFF-BOARD COUNTERMEASURES BRANCH

(U) An Investigation of the Aerodynamic Performance of the Spin-Wing Concept

DESCRIPTIVE NOTE: Interim report.
27 FEB 1998 17 PAGES
PERSONAL AUTHORS: Tayman, Steven K.; Walden, Andrea B.

UNCLASSIFIED REPORT

ABSTRACT: (U) Unmanned Air Vehicles (UAV's) capable of Vertical Takeoff and Landing (VTOL) are always of interest to the Navy. This paper examines the aerodynamic performance of a unique multi-mode aircraft concept called the spin-wing/stop rotor. The spin wing uses its wing and tail as a counter-rotating rotor system for hovering flight. For forward flight, the wing and tail are stopped.

DESCRIPTORS: (U) *AERODYNAMIC CHARACTERISTICS, AIRCRAFT, FLIGHT, UNMANNED, TAKEOFF, MULTIMODE, SPINNING(MOTION), LEVEL FLIGHT, WINGS, HOVERING, VERTICAL TAKEOFF AIRCRAFT.

IDENTIFIERS: (U) UAV(UNMANNED AIR VEHICLES), VTOL (VERTICAL TAKEOFF AND LANDING), SPIN-WING/STOP ROTOR.

♦AD-A339467/JAA

ARMY COMMAND AND GENERAL STAFF COLL
FORT LEAVENWORTH KS SCHOOL OF ADVANCED MILITARY STUDIES

(U) Medusa's Mirror: Stepping Forward to Look Back "Future UAV Design Implications from the 21st Century Battlefield"

DESCRIPTIVE NOTE: Monograph
18 DEC 1997 68 PAGES
PERSONAL AUTHORS: Brown, David A.

UNCLASSIFIED REPORT

ABSTRACT: (U) This paper intends to explore the differences between a general purpose and a functional design approach, and will attempt to answer the question of which of these approaches will best serve the needs of the services on the twenty-first century battlefield. Currently, UAVs are seen in the Army as generic intelligence gathering devices which can be tailored to the mission at hand. Fielding a general purpose UAV retains a certain amount of flexibility in the way that we have initially integrated the UAV concept another possible alternative is to build functionally specific UAV designs, each for a different purpose.

DESCRIPTORS: (U) *MILITARY INTELLIGENCE, *MILITARY STRATEGY, MILITARY OPERATIONS, BATTLEFIELDS, JOINT MILITARY ACTIVITIES, UNMANNED, MILITARY APPLICATIONS, INTERNATIONAL, REMOTELY PILOTED VEHICLES, TECHNOLOGY FORECASTING.

IDENTIFIERS: (U) MONOGRAPH, UAV(UNMANNED AERIAL VEHICLES), JOINT VISION 2010

♦ Included in The DTIC Review, September 1998.

AD-A337401/JAA

RAND CORP
SANTA MONICA CA

(U) The Predator ACTD; A Case Study for Transition Planning to the Formal Acquisition Process

1997 107 PAGES
PERSONAL AUTHORS: Thirtle, Michael R.; Johnson, Robert V.; Birkler, John L.

UNCLASSIFIED REPORT

ABSTRACT: (U) In July 1995, a new endurance Unmanned Aerial Vehicle (UAV) flew over Bosnia to surveil and provide all-weather reconnaissance and image-gathering in an operational (i.e., conflict) environment. Representing a new capability for the Department of Defense (DoD), this UAV represented, above all, a Departure from DoD's usual way of doing acquisition business. The study documented in this report was completed in support of RAND Research on Advanced Concept Technology Demonstration (ACTD) Programs for the Office of the Secretary of Defense. The effort was conducted from July until December 1996 and documents research on the Medium Altitude Endurance (MAE) Unmanned Aerial Vehicle ACTD Program, also known as the Predator UAV. Specifically, RAND was tasked to examine two questions: (1) What were the overarching lessons learned from the Predator ACTD? and (2) Which lessons can be generalized and applied to other ACTD programs? In this analysis, we closely detail the Predator ACTD and also document the important demonstration and transition issues from the project that can be applied to other ACTDs. The intent of this work is to improve the ACTD process and the transition of ACTDs to Formal Acquisition Programs. This report should be of interest to those involved in acquisition, program offices, and ACTD programs.

DESCRIPTORS: (U) *AIRCRAFT, *UNMANNED, DEPARTMENT OF DEFENSE, LESSONS LEARNED, ACQUISITION, DEMONSTRATIONS, ENDURANCE(GENERAL), CASE STUDIES, PLANNING, RECONNAISSANCE, ALL WEATHER, MEDIUM ALTITUDE.

IDENTIFIERS: (U) *ACTD(ADVANCED CONCEPT TECHNOLOGY DEMONSTRATION), UAV(UNMANNED AERIAL VEHICLE).

◆**AD-**A336710/JAA

OFFICE OF THE UNDER SECRETARY OF DEFENSE (ACQUISITION AND TECHNOLOGY)
WASHINGTON DC

(U) UAV Annual Report, FY 1997.

DESCRIPTIVE NOTE: Annual report
1997 48 PAGES

UNCLASSIFIED REPORT

ABSTRACT: (U) The U.S. Military faces a challenging future in an era of dynamic change, constrained resources, potential new roles, and rapid technological advancement. These factors require innovative thinking and new ways to shape change. UAV's will help us shape this change. They represent both a revolution in military affairs and a revolution in business affairs. The capacity to dominate any adversary and control any situation in any operation will be the key capability we ask of our armed forces in the 21st century. UAV's' will provide a sustained responsive, accurate picture of the battlefield.

DESCRIPTORS: (U) *AERIAL RECONNAISSANCE, *UNMANNED, *REMOTELY PILOTED VEHICLES, *RECONNAISSANCE AIRCRAFT, MILITARY STRATEGY, NATIONAL SECURITY, STRATEGIC INTELLIGENCE.

IDENTIFIERS: (U) *UAV(UNMANNED AERIAL VEHICLES), ISR(INTELLIGENCE SURVEILLANCE RECONNAISSANCE)

◆ Included in TheDTIC Review, September 1998.

AD-A335135/JAA

JOINT PUBLICATIONS RESEARCH SERVICE
ARLINGTON, VA

(U) Development of Onboard Data Acquisition for Unmanned Air Vehicle Flight Testing.

DESCRIPTIVE NOTE: Master's thesis,
DEC 1996 138 PAGES
PERSONAL AUTHORS: Merola, Joseph M.

UNCLASSIFIED REPORT

ABSTRACT: (U) An off-the-shelf data logger was used as the basis to evolve software and hardware installations providing a simple, reliable data recording system for UAV flight tests. Wiring harnesses, circuit board and plug designs, as well as controlling software were developed for general installations. The recorder is housed in a 4x2.Sxl .5 inch box which can be conveniently installed or removed in any UAV. It is capable of storing up to 512k of data at sampling rates up to 3200 Hz with eight, 12-bit analog channels. A set of MATLAB commands was developed to allow convenient processing and analysis of recorded data. Numerous ground and bench tests were conducted as well as flight tests.

DESCRIPTORS: (U) *FLIGHT TESTING, *UNMANNED, *DATA ACQUISITION, *ONBOARD, COMPUTER PROGRAMS, DATA PROCESSING, RATES, RELIABILITY, SAMPLING, RECORDING SYSTEMS, BENCH TESTS.

IDENTIFIERS: (U) *UAV(UNMANNED AIR VEHICLE)

AD-A334778/JAA

DEPARTMENT OF THE AIR FORCE
WASHINGTON DC

(U) Operational Requirements Document for the Unmanned Aerial Vehicle (UAV) Tactical Control System (TCS) Version 3.0

1996 10 PAGES

UNCLASSIFIED REPORT

ABSTRACT: (U) The requirement relates to the Office for the Under Secretary of Defense (Acquisition and Technology) Mission Areas 212 (Indirect Fire Support), 217 (Land Warfare Surveillance and Reconnaissance), 223 (Close Air Support and Interdiction), 227 (Air Warfare Surveillance and Reconnaissance), 232 (Amphibious, Strike, and Antisurface Warfare), 237 (Naval Warfare Surveillance and Reconnaissance), 322 (Tactical Intelligence and Related Activities (TIARA) for Tactical Land Warfare), 345 (Tactical Communications), 370 (Electronic Combat) and 373 (Tactical Surveillance, Reconnaissance, and Target Acquisition). The Tactical Control System (TCS) is the Software, Software- related hardware and the extra ground support hardware (antennae, cabling, etc.) necessary for the control of the Tactical Unmanned Aerial Vehicle (TUAV), and Medium Altitude Endurance (MAE) UAV, and future tactical UAVs. The TCS will also provide connectivity to identified Command, Control, Communications, Computers and Intelligence (C4I) systems. TCS will have the objective capability of receiving high altitude endurance (MAE) UAV payload information. Although developed as a total package, the TCS will have the capability to be configured and down- scaled to meet the user's deployability or operator limitations.

DESCRIPTORS: (U) *MILITARY REQUIREMENTS, *REMOTELY PILOTED VEHICLES, *TACTICAL COMMUNICATIONS, ELECTRONIC WARFARE, LAND WARFARE, COMBAT SURVEILLANCE, TARGET ACQUISITION, MILITARY VEHICLES, AERIAL WARFARE, TACTICAL AIR SUPPORT, TACTICAL RECONNAISSANCE, UNMANNED, HIGH ALTITUDE, NAVAL WARFARE, OPERATORS (PERSONNEL), GROUND SUPPORT, TACTICAL WARFARE, ANTISHIP WARFARE, TACTICAL INTELLIGENCE.

IDENTIFIERS: (U) ORD (OPERATIONAL REQUIREMENTS DOCUMENT)

AD-A333445/JAA

NAVAL POSTGRADUATE SCHOOL
MONTEREY CA

(U) Evaluation of the CMARC Panel Code Software Suite for the Development of a UAV Aerodynamic Model

DESCRIPTIVE NOTE: Master's thesis
JUN 1997 151PAGES
PERSONAL AUTHORS: Pollard, Stephen J.

UNCLASSIFIED REPORT

ABSTRACT: (U) The CMARC panel code is evaluated to verify its accuracy and suitability for the development of an aerodynamic model of the Naval Postgraduate School (NPS) FROG Unmanned Air Vehicle (UAV). CMARC is a dos personal computer based version of the NASA Panel Method Ames Research Center (PMARC) panel code. The core processing algorithms in CMARC are equivalent to PMARC. CMARC enhancements include improved memory management and command line functionality. Both panel codes solve for Inviscid, incompressible flow over complex three-dimensional bodies using potential flow theory. Emphasis is first placed on verifying CMARC against the PMARC and NPS Unsteady Potential Flow (UPOT) panel codes. CMARC boundary layer calculations are then compared to experimental data for an inclined prolate spheroid. Finally, a complex three- dimensional panel model is developed for aerodynamic modeling of the FROG UAV. CMARC off-body flow field calculations are used to generate static-source and angle-of-attack vane position corrections. Position corrections are provided in look-up table and curve fit formats. Basic longitudinal and lateral-directional stability derivatives are also developed with CMARC data. CMARC derived stability derivatives are sufficiently accurate for incorporation into an initial aerodynamic model.

DESCRIPTORS: (U) *COMPUTATIONAL FLUID DYNAMICS, *COMPUTER PROGRAM VERIFICATION, *AERODYNAMICS, SOFTWARE ENGINEERING, AERODYNAMIC STABILITY, THESES, BOUNDARY LAYER, FLOW FIELDS, HYDRODYNAMIC CODES, AIRCRAFT MODELS, INVISCID FLOW, REMOTELY PILOTED VEHICLES, INCOMPRESSIBLE FLOW, POTENTIAL FLOW, THREE DIMENSIONAL FLOW.

IDENTIFIERS: (U) UNMANNED AERIAL VEHICLES, PANEL CODES, CMARC COMPUTER PROGRAM.

AD-A333402/JAA

NAVAL POSTGRADUATE SCHOOL
MONTEREY CA

(U) Incorporation of a Differential Positioning System (DGPS) In The Control of an Unmanned Aerial Vehicle (UAV) for Precise Navigation in the Local Tangent Plane (LTP)

DESCRIPTIVE NOTE: Master's thesis
MAR 1997 74 PAGES
PERSONAL AUTHORS: Allen, Peyton M.

UNCLASSIFIED REPORT

ABSTRACT: (U) The purpose of this thesis is to incorporate the global positioning system (GPS) and Inertial Navigation System (INS), for the guidance of an Unmanned Aerial Vehicle (UAV) seeking precise navigation in a Local Tangent Plane (LTP). By applying the Differential Positioning technique, GPS position data becomes more accurate. This position can then be referenced to a known location on the ground in order to give the aircraft's position in the local tangent plane. The FOG-R UAV at the Naval Postgraduate School will be used for autonomous flight testing using a Texas Instruments TMS320C30 Digital Signal Processor (DSP). This DSP is hosted on an IBM compatible PC, and is controlled via integrated system's AC100 control system design and implementation software package. The GPS receiver used throughout this thesis is a Motorola PVT-6 OEM. Another identical GPS receiver is used as a reference station, thus providing the differential capability. The objectives of this thesis are: The system must be able to accept current location from the GPS and convert it to LTP, display the LTP coordinates, numerically and graphically, and be able to easily change the origin coordinates. Finally, the achieved accuracy of the differential setup is examined.

DESCRIPTORS: (U) AIR NAVIGATION, *GLOBAL POSITIONING SYSTEM, *INERTIAL NAVIGATION, *REMOTELY PILOTED VEHICLES, COMPUTER PROGRAMS, STATIONS, FLIGHT TESTING, POSITION(LOCATION), INTEGRATED SYSTEMS, THESES, POSITION FINDING, UNMANNED, SELF OPERATION, TANGENTS, HOMING.

♦**AD**-A332349/JAA

AIR COMMAND AND STAFF COLL
MAXWELL AFB AL

(U)STRIKESTAR 2025.

DESCRIPTIVE NOTE: Research paper,
AUG 1996 90 PAGES
PERSONAL AUTHORS: Carmichael, Bruce W.; Devine, Troy E.; Kaufman, Robert J.; Pence, Patrick E.; Wilcox, Richard S.

UNCLASSIFIED REPORT

ABSTRACT: (U) We examined Unmanned Aerial Vehicles (UAV), knowing that similar research had produced naysayers and even some active hostility. However, we are genuinely concerned for future modernization efforts as budgets and manpower decrease. We came to an early conclusion that manned vehicles provide a flexibility and level of accountability far beyond that of unmanned vehicles. But considering our changing world, the use of unmanned vehicles for missions beyond reconnaissance is both technically feasible and cost-attractive. We envision the UAV proposed here to be a force multiplier for the air and space warrior-a new tool in the warrior's arsenal.

DESCRIPTORS: (U) *MILITARY REQUIREMENTS, *VEHICLES, *UNMANNED SPACECRAFT, MILITARY INTELLIGENCE, MILITARY OPERATIONS, MILITARY HISTORY, AIRCRAFT, MISSIONS, BUDGETS, RECONNAISSANCE, ACCOUNTABILITY.

IDENTIFIERS: (U) UAV(UNMANNED AERIAL VEHICLES), *STRIKESTAR

AD-A331969/JAA

NAVAL POSTGRADUATE SCHOOL
MONTEREY CA

(U) Development of a Dynamic Model for a UAV

DESCRIPTIVE NOTE: Master's thesis,
MAR 1997 116 PAGES
PERSONAL AUTHORS: Papageorgiou, Evangelos C.

UNCLASSIFIED REPORT

ABSTRACT: (U) Moments of inertia were experimentally determined and the longitudinal and lateral/directional static and dynamic stability and control derivatives were estimated for a fixed wing Unmanned Air Vehicle (UAV). High fidelity, non-linear equations of motion were derived and tailored for use on the specific aircraft. Computer modeling of these resulting equations was employed both in Matlab/Simulink and in Matrix(sub x)/systembuild. The resulting computer model was linearized at a specific flight condition, and the dynamics of the aircraft were predicted. Several flight tests were conducted at a nearby airfield and the behavior of the aircraft was compared to that of the computer model. The longitudinal dynamics as depicted by the short period mode were found to be almost identical with those predicted by the non-linear computer model. The phugoid mode was also observed and found to be in close agreement. In the lateral/directional dynamics, flight test was employed to improve the model and the parameters were modified to obtain a better math. Ultimately a reasonably accurate non-linear model was achieved as required for purposes of control and navigation system design.

DESCRIPTORS: (U) *MATHEMATICAL MODELS, *FLIGHT TESTING, *NONLINEAR DIFFERENTIAL EQUATIONS, COMPUTERIZED SIMULATION, EQUATIONS OF MOTION, AIRCRAFT, COMPUTERS, DYNAMICS, ACCURACY, NONLINEAR SYSTEMS, NAVIGATION, UNMANNED, MATHEMATICS, EQUATIONS, FLIGHT SIMULATION, NONLINEAR PROGRAMMING, DIRECTIONAL, MOMENT OF INERTIA.

IDENTIFIERS: (U) *UAV(UNMANNED AERIAL VEHICLE)

♦ Included in The DTIC Review, September 1998.

AD-A329483/JAA

GENERAL ACCOUNTING OFFICE
WASHINGTON DC
NATIONAL SECURITY AND
INTERNATIONAL AFFAIRS DIV

(U) Unmanned Aerial Vehicles; Outrider Demonstrations will be Inadequate to Justify Further Production.

SEP 1997 21 PAGES

UNCLASSIFIED REPORT

ABSTRACT: (U) The Department of Defense (DoD) has undertaken a number of efforts in the past to acquire Unmanned Aerial Vehicles (UAVs) to complement its mix of manned and national reconnaissance assets. Our previous reviews of UAV programs have shown that DoD's acquisition efforts to date have been disappointing. This report discusses the outrider, a UAV system, which DoD is acquiring through a streamlined acquisition process known as an Advanced Concept Technology Demonstration (ACTD). We examined whether (1) DoD is applying lessons learned from prior UAV programs to the outrider and (2) The outrider is likely to meet user needs. UAVs are pilotless aircraft, controlled remotely or by preprogrammed on- board equipment. The outrider system consists of four air vehicles, ground control equipment, one remote video terminal, four modular mission payloads, communications devices, a means of launch and recovery, and one mobile maintenance facility for every three outrider systems. The outrider ACTD grew out of the Joint Tactical UAV program. The original concept of the Joint Tactical UAV Program was to acquire (1) A 50-kilometer UAV system, the maneuver, to satisfy reconnaissance and surveillance needs of Army Brigade and Marine Corps Regimental Commanders and (2) A 200-kilometer UAV system, the hunter, to satisfy the reconnaissance and surveillance needs of Army Corps and Division Commanders and Navy Task Force Commanders.

DESCRIPTORS: (U) *COST ESTIMATES, *UNMANNED, *REMOTELY PILOTED VEHICLES, *RECONNAISSANCE AIRCRAFT, AERIAL RECONNAISSANCE, DEPARTMENT OF DEFENSE, MILITARY REQUIREMENTS, ACQUISITION, USER NEEDS.

IDENTIFIERS: (U) GAO REPORTS, UAV(UNMANNED AERIAL VEHICLES).

AD-A329477/JAA

AMERICAN INST OF AERONAUTICS AND ASTRONAUTICS
NEW YORK

(U) Support of AIAA Student Aircraft Design/Fly Competition.

DESCRIPTIVE NOTE: Final report 1 APR-31 DEC 97
1 AUG 1997 481 PAGES
PERSONAL AUTHORS: Page, Gregory S.; Bovias, Chris; Selig, Michael; Vargas, Wil

UNCLASSIFIED REPORT

ABSTRACT: (U) This report is made up of the combined reports of eight separate teams of students who entered the 1997 Design, Build & Fly Competition. The objectives of the competition were to have student teams design, build and fly unmanned remote control electric aircraft designed for maximum range on a limited battery. A "fly- off" took place on a private airstrip at Ragged Island, MD, in April 1997. Winners of the contest: 1st place, University of Illinois at Urbana-Champaign; 2nd, Virginia Polytechnic Institute and University; 3rd, Texas A&M University. The Design, Build & Fly Competition was supported by CESSNA, the Office of Naval Research and the AIAA Foundation.

DESCRIPTORS: (U) *REMOTELY PILOTED VEHICLES, *AIRCRAFT DESIGN, STUDENTS, UNMANNED, ELECTRIC POWER, ELECTRIC MOTORS.

IDENTIFIERS: (U) *DESIGN COMPETITION.

AD-A329325/JAA

AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH
SCHOOL OF ENGINEERING

(U) Improved Load Alleviation Capability for the KC-135.

DESCRIPTIVE NOTE: Master's thesis
SEP 1997 144 PAGES
PERSONAL AUTHORS: Mortensen, Adam L.

UNCLASSIFIED REPORT

ABSTRACT: (U) The Air Force will greatly increase its use of Unmanned Aerial Vehicles (UAVs) in the next century and the latter part of this decade. These UAVs will require refueling like their manned counterparts. The KC-135 and the KC-10 are candidates to provide this refueling task. The KC-10 is equipped with an automatic load alleviation system on its refueling boom which minimizes radial loads at the receiver of the aircraft being refueled. The KC-135 does not have such a system on its boom. Because the boom operator relies on visual cues to tell him when the boom is bending to adjust the boom's ruddevators, large loads may be imparted to receiver aircraft at the fuel receiver port. While load alleviation is required for all aircraft in order to ensure that binding of the nozzle does not prevent disconnect, load alleviation may also be important for the lightweight UAV in order to prevent unwanted disturbance to its flight control system. A controller was designed to control the longitudinal motion of the boom. This controller can control the angle of the boom so no forces are imparted to the nozzle as the tanker moves from its nominal orientation. The optimal controller design uses both feed forward and rate feedback to modulate the commanded torque signal sent to the ruddevators. The results show that using an automatic controller promises to provide accurate control of the KC-135 refueling boom during refueling operations with minimal nozzle forces being imparted to the receiver aircraft.

DESCRIPTORS: (U) *BOOMS(EQUIPMENT), *REFUELING IN FLIGHT, SIMULATION, ROBOTICS, ADAPTIVE CONTROL SYSTEMS, AUTOMATION, LOADS(FORCES), TANKER AIRCRAFT, NOZZLES, RADIAL STRESS.

IDENTIFIERS: (U) *REFUELING EQUIPMENT, UAV(UNMANNED AERIAL VEHICLES), KC-135 AIRCRAFT, RUDDEVATORS, BOOM CONTROLLERS,AUTOMATIC CONTROL

◆**AD**-A329050/JAA

AIR UNIV
MAXWELL AFB AL

(U) Unmanned Aerial Vehicles and Weapons of Mass Destruction: A Lethal Combination?

AUG 1997 50 PAGES
PERSONAL AUTHORS: Renehan, Jeffrey N.

UNCLASSIFIED REPORT

ABSTRACT: (U) This study analyzes the characteristics and capabilities of Unmanned Aerial Vehicles (UAV) to determine their capability to carry Weapons of Mass Destruction (WMD). The author presents an overview of the various forms of WMD chemical, biological, and nuclear weapons. The objective is to review the characteristics of both UAVs and WMD to determine if they are capable of being used together as an effective weapon. The result indicates that there is great potential for the use of UAVs as delivery systems for WMD, particularly by developing nations and nonstate actors such as terrorist groups who may not have the technical capability to employ other means. The potential exists for the proliferation of both UAVs and WMD to become widespread and thus a major security concern. There is no clear solution to this problem; however, actions including bringing the issue to the forefront, strengthening export and arms controls, deterrence, and defense will have a synergistic effect that will help mitigate this threat.

DESCRIPTORS: (U) *MASS DESTRUCTION WEAPONS, *REMOTELY PILOTED VEHICLES, *WEAPON DELIVERY, *AERIAL DELIVERY, NUCLEAR WEAPONS, DEVELOPING NATIONS, DELIVERY, THREATS, ARMS CONTROL, TERRORISM, SYNERGISM.

◆ Included in The DTIC Review, September 1998.

AD-A328322/JAA

GENERAL ACCOUNTING OFFICE
WASHINGTON DC
NATIONAL SECURITY AND
INTERNATIONAL AFFAIRS DIV

(U) Unmanned Aerial Vehicles: DoD's Acquisition Efforts.

APR 1997 19 PAGES

UNCLASSIFIED REPORT

ABSTRACT: (U) According to DoD, its objective in acquiring UAVs is to provide unmanned systems that will complement its mix of manned and national reconnaissance assets. However, its UAV acquisition efforts to date have been disappointing. Since Aquila began in 1979, of eight UAV programs, three have been terminated (Aquila, Hunter, Medium range), three remain in development (Outrider, Global Hawk, Darkstar), and one is now transitioning to low rate production (Predator). Only one of the eight, pioneer, has been fielded as an operational system. We estimate DoD has spent more than $2 billion for development and/or procurement on these eight UAV programs over the past 18 years.

DESCRIPTORS: (U) *REMOTELY PILOTED VEHICLES, ACQUISITION, PRODUCTION, MILITARY PROCUREMENT, LOW RATE.

AD-A327682/JAA

AIR UNIV
MAXWELL AFB AL

(U) 2025 Operational Analysis.

DESCRIPTIVE NOTE: Research paper,
JUN 1996 51 PAGES
PERSONAL AUTHORS: Jackson, Jack A, Jr.; Jones, Brian L.; Lehmkuhl, Lee J.

UNCLASSIFIED REPORT

ABSTRACT: (U) In the summer of 1995 the Air Force Chief of Staff tasked Air University to do a year long study, 2025, to generate ideas and concepts on the capabilities the United States will require to possess the dominant air and space forces in the future, detail new or high leverage concepts for employing air and space power, and to detail technologies required to enable the capabilities envisioned. To support this goal a 2025 study team conducted an operational analysis to identify high value system concepts and their enabling technologies in a way that was objective, traceable, and robust. This analysis determined which of the 2025 system concepts show the greatest potential for enhancing future air and space capabilities and which embedded technologies have the highest leverage in making the high value system concepts a reality. The 2025 study produced a number of excellent system concepts for employing air and space power in the future. Analysis of the highest value system concepts indicated that the effort to occupy the high ground of the future will require air and space forces to possess increased awareness and to control the medium of space.

DESCRIPTORS: (U) *AIR POWER, *SPACE WARFARE, *NATIONAL DEFENSE, *TECHNOLOGY FORECASTING, AERIAL RECONNAISSANCE, MANAGEMENT INFORMATION SYSTEMS, AIR FORCE RESEARCH, SPACE SURVEILLANCE, COMBAT READINESS, GLOBAL POSITIONING SYSTEM, MILITARY CAPABILITIES, AIR LAUNCHED, AIR FORCE PLANNING, SPACE COMMUNICATIONS, UNMANNED SPACECRAFT.

IDENTIFIERS: (U) MONOGRAPHS, UAV(UNMANNED AERIAL VEHICLES).

AD-A327218/JAA

ARETE ASSOCIATES
ARLINGTON VA

(U) Development of an EO Wave Imaging System on Pelican, A Remotely Piloted Aircraft.

DESCRIPTIVE NOTE: Final report
30 MAY 1997 29 PAGES
PERSONAL AUTHORS: Selwyn, Philip; Jendro, Larry; Farruggia, Guy

UNCLASSIFIED REPORT

ABSTRACT: (U) In this report Arete proposes the development of an electro-optical wave imaging system and its installation on the pelican remotely piloted aircraft. This system would collect a time series of electro-optical images over a precisely fixed area of the ocean to provide wave spectra which would be analyzed to determine important coastal ocean parameters such as bathymetry, wave characteristics and surface currents. The coastal-zone of the ocean is spatially and temporally complex, exhibiting a number of physical processes occurring simultaneously. Specific items of interest include ocean swell, wind-driven waves, mean and variance in turbulent fluxes, breaking waves and currents. In the coastal zone, the situation is complicated by significant spatial gradients that cause inhomogeneities on relatively small spatial scales. Although small on geophysical scales, these coastal features are too extensive and complex to be measured well by a small number of research vessels or buoys, yet they are too small and vary too rapidly to be measured by satellite sensors. What is needed is an instrument system that can measure many of the required parameters, but is small and lightweight so that it can be mounted in an aircraft and therefore cover a wide area of interest over relatively long span of time.

DESCRIPTORS: (U) *ELECTROOPTICS, *REMOTELY PILOTED VEHICLES, DIGITAL SYSTEMS, SPATIAL DISTRIBUTION, COASTAL REGIONS, OCEAN WAVES, DETECTORS, AIRCRAFT, PARAMETERS, WIND, TIME SERIES ANALYSIS, TURBULENCE, SURFACES, BATHYMETRY, SPECTRA, SCALE, IMAGES, MILITARY CAPABILITIES, ARTIFICIAL SATELLITES, CAMERAS, INSTRUMENTATION, GEOPHYSICS, WAVES, CURRENTS, GRADIENTS, BUOYS, GUN TURRETS, RESEARCH SHIPS.

AD-A326936/JAA

ARMY WAR COLL
CARLISLE BARRACKS PA

(U) Unmanned Aerial Vehicles - Promises and Potential.

DESCRIPTIVE NOTE: Research report,
APR 1997 47 PAGES
PERSONAL AUTHORS: Sosa, Arthur J.

UNCLASSIFIED REPORT

ABSTRACT: (U) This paper reviews the background of Unmanned Aerial Vehicles (UAV), tracing UAV technology from its genesis through to the promising UAV systems in development today. It provides historical insight into the enabling technologies which make UAVs uniquely capable of a variety of missions beyond their traditional roles in aerial reconnaissance. Finally, the controversy over manned vs. unmanned aircraft is raised to shake up the cultural inertia which seems to constrain UAV applications in the revolution in military affairs. Regardless of the winner of that debate, UAV systems are politically and fiscally relevant to our military today and in the uncertain future.

DESCRIPTORS: (U) *SURVIVABILITY, *REMOTELY PILOTED VEHICLES, AERIAL RECONNAISSANCE, MILITARY REQUIREMENTS, PAYLOAD, PILOTS, MILITARY CAPABILITIES, UNMANNED, MASS DESTRUCTION WEAPONS, AVIATION SAFETY.

IDENTIFIERS: (U) UNMANNED AERIAL VEHICLES.

AD-A325830/JAA

NAVAL WAR COLL
NEWPORT RI
JOINT MILITARY
OPERATIONS DEPT

(U) UAVs for the Operational Commander: Beyond Tactical Reconnaissance, Surveillance and Target Acquisition (RSTA).

DESCRIPTIVE NOTE: Final report
7 FEB 1997 25 PAGES
PERSONAL AUTHORS: Thom, Maxie C.

UNCLASSIFIED REPORT

ABSTRACT: (U) Joint publication 3-55, doctrine for Reconnaissance, Surveillance, and Target Acquisition (RSTA) and 3-55.1, Joint Tactics, Techniques, and Procedures (JTTP) for Unmanned Aerial Vehicles (UAVs), consider UAVs as tactical assets. As joint publications, they have an obligation to establish a framework to guide the employment of joint forces and provide a basis for joint training to enhance the effectiveness of joint operations. The tactical focus of joint doctrine for UAV employment is echoed in other joint doctrinal publications to include joint pub 2-0, intelligence support to joint operations. This myopic focus inhibits the integration of UAVs into sequenced and synchronized joint operations, thereby, limiting their ability to conduct operations at the operational and strategic levels of war. Current UAV doctrine must be changed in order for commanders to realize the full potential of UAVs to enhance joint operations. Only then can an adequate framework for employment and training be established to allow a joint force commander to integrate UAVs into the planning, preparing, conducting, and sustaining of joint forces to accomplish operational or strategic objectives through the conduct of campaigns and major operations.

DESCRIPTORS: (U) *MILITARY DOCTRINE, *TARGET ACQUISITION, *TAC RECONNAISSANCE, *SURVEILLANCE, INTELLIGENCE, AIRCRAFT, EMPLOYMENT, TRAINING, JOINT MILITARY ACTIVITIES, DOCUMENTS, UNMANNED, SYNCHRONISM, MILITARY TACTICS, REMOTELY PILOTED VEHICLES.

AD-A324146/JAA

AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH
SCHOOL OF ENGINEERING

(U) Applying Tabu Heuristic to Wind Influenced, Minimum Risk and Maximum Expected Coverage Routes.

DESCRIPTIVE NOTE: Master's thesis
FEB 1997 83 PAGES
PERSONAL AUTHORS: Sisson, Mark R.

UNCLASSIFIED REPORT

ABSTRACT: (U) The purpose of this thesis is to provide air combat command a method for determining the number of predator Unmanned Aerial Vehicles (UAVs) required to cover a pre-selected target. Extending previous research that employs reactive tabu search methods for deterministic vehicle routing problems, this thesis incorporates wind effects that can significantly alter the travel times for any given scenario. Additionally, it accounts for possible attrition by introducing minimum risk route and expected number of target covered to the objective function. The results of the tabu search and subsequent monte-carlo simulation: gives the number of predator's required to cover a target set, identifies robust' routes, and suggests routes that increase expected number of targets covered while reducing losses.

DESCRIPTORS: (U) *AERIAL WARFARE, *DEFENSE PLANNING, AERIAL RECONNAISSANCE, RISK, TRAFFIC, ATTRITION, THESES, MONTE CARLO METHOD, SEARCHING, UNMANNED, SELF OPERATION, HEURISTIC METHODS, ROUTING, AREA COVERAGE, DETERMINANTS(MATHEMATICS), TRAVEL TIME.

IDENTIFIERS: (U) TRAVELING SALEMAN PROBLEMS.

AD-A324133JAA

AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH

(U) Optimizing Airborne Area Surveillance Asset Placement.

DESCRIPTIVE NOTE: Master's thesis
18 FEB 1997 118 PAGES
PERSONAL AUTHORS: Fuller, Douglas E.

UNCLASSIFIED REPORT

ABSTRACT: (U) Currently there is no automated planning tool for the optimum positioning of USAF area surveillance assets for a theater level campaign. This research seeks to find the optimum or near optimum placement of the limited USAF airborne surveillance assets against a theater level target set. The problem of finding the optimum orbit points can be modeled as a classic maximal covering location problem (MCLP). Operational constraints on the placement of surveillance aircraft can be handled by preprocessing the potential orbit points to eliminate infeasible orbit points. Heavy emphasis is placed on preprocessing the data to reduce problem size and hence solution time. The aggregation of both the potential orbit points and targets was accomplished without loss of locational information. An existing heuristic was used to find a solution in a very short time. The heuristic finds the optimum orbit points for the available aircraft and any alternate solutions. Allocation decisions can then be accomplished.

DESCRIPTORS: (U) *OPTIMIZATION, *SURVEILLANCE, *PATROL AIRCRAFT, AERIAL RECONNAISSANCE, POSITION(LOCATION), THEATER LEVEL OPERATIONS, AUTOMATION, DECISION MAKING, SIZES(DIMENSIONS), SHORT RANGE(TIME), SOLUTIONS(GENERAL), PLANNING, POSITION FINDING, EMPLACEMENT, ALLOCATIONS, HEURISTIC METHODS, GEOGRAPHIC AREAS, SURFACE TARGETS.

IDENTIFIERS: (U) MCLP(MAXIMAL COVERING LOCATION PROBLEM), E-3 AIRCRAFT, AWACS(AIRBORNE WARNING AND CONTROL SYSTEM), JOINT STARS(JOINT SURVEILLANCE AND TARGET ATTACK RADAR SYSTEM).

AD-A323870/JAA

GENERAL ACCOUNTING OFFICE
WASHINGTON DC
NATIONAL SECURITY AND
INTERNATIONAL AFFAIRS DIV

(U) Unmanned Aerial Vehicles DoD's Acquisition Efforts.

9 APR 1997 18 PAGES

UNCLASSIFIED REPORT

ABSTRACT: (U) I am pleased to be here today to briefly discuss the Unmanned Aerial Vehicle (UAV) acquisition efforts that the Department of Defense (DoD) has undertaken over the past 15 years. My comments are based on our reviews of a number of UAV programs. After a short summary, I would like to present you with a chronological discussion of the descriptions and outcomes of some of these programs, and then provide you with some key observations about DoD's UAV acquisition efforts. According to DoD, its objective in acquiring UAV's is to provide unmanned systems that will complement its mix of manned and national reconnaissance Assets. However, its UAV acquisition efforts to date have been disappointing. Since Aquila began in 1979, of eight UAV programs, three have been terminated, three remain in development, and one is now transitioning to low rate production. Only one of the eight, Pioneer, has been fielded as an operational system. We estimate DoD has spent more than $2 billion for development and/or procurement on eight UAV programs over the past 18 years.

DESCRIPTORS: (U) *COST ESTIMATES, *REMOTELY PILOTED VEHICLES, *RECONNAISSANCE AIRCRAFT, AERIAL RECONNAISSANCE, DEPARTMENT OF DEFENSE, MILITARY REQUIREMENTS, MANAGEMENT PLANNING AND CONTROL, UNMANNED, MILITARY PROCUREMENT, REMOTE CONTROL, NATIONAL DEFENSE.

IDENTIFIERS: (U) GAO REPORTS, UNMANNED AERIAL VEHICLES.

AD-A323187/JAA

AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH
SCHOOL OF ENGINEERING

(U) Automatic Digital Processing for Calibration Data of Open Skies Treaty Sensors.

DESCRIPTIVE NOTE: Master's thesis
MAR 1997 128 PAGES
PERSONAL AUTHORS: Keating, Donna D.

UNCLASSIFIED REPORT

ABSTRACT: (U) The open skies treaty provides guidelines allowing participants to fly in air space over other participants' countries to monitor strategic military placement and development. The treaty restricts the ground size of the smallest detail recorded by these aerial imaging systems to any size larger than 30 cm. This restriction is enforced by placing a lower limit on the altitude at which a participating aircraft can fly and it is computed as the value of Hmin. Current techniques rely on human photographic interpreters to select the value of Hmin for every calibration pass and is very resource intensive. The open skies participants are investigating machine based techniques to supplement the traditional human role in an effort to increase the objectiveness of the measurement. This thesis presents a software tool called, ADMIN, a man-in-the-loop, algorithm which manipulates image statistics to identify the orientation and width of individual target bar groups from digitized images of aerial photographs of open skies treaty calibration triple bar target. ADMIN Hmin results achieved an 88.6 percent correlation with the open skies media processing facility's Hmin computations.

DESCRIPTORS: (U) *IMAGE PROCESSING, *AERIAL PHOTOGRAPHY, ALGORITHMS, SIGNAL PROCESSING, SOFTWARE ENGINEERING, AERIAL RECONNAISSANCE, DATA MANAGEMENT, TARGET RECOGNITION, THESES, OPTICAL IMAGES, PHOTOGRAMMETRY, CALIBRATION, OPTICAL DETECTORS, PIXELS, REMOTE DETECTION, DIGITAL COMPUTERS, PHOTOGRAPHIC IMAGES.

IDENTIFIERS: (U) MAN IN THE LOOP, ADIM COMPUTER PROGRAM.

AD-A322382/JAA

NAVAL POSTGRADUATE SCHOOL
MONTEREY CA

(U) Uniform System for the Rapid Prototyping and Testing of Controllers for Unmanned Aerial Vehicles.

DESCRIPTIVE NOTE: Master's thesis
SEP 1996 97 PAGES
PERSONAL AUTHORS: Zanino, James A.

UNCLASSIFIED REPORT

ABSTRACT: (U) The field of control systems has witnessed an explosion in state-space techniques addressing a variety of critical design issues facing control engineers today. Modem computational tools, such as the Matrix(x) product family developed by Integrated Systems Incorporated, allow the designer to quickly design, test and implement control systems based on these state-space techniques. These new computing advances shorten the time required to complete a control design from a few years to a few months. However, as the design process progressed new inputs and outputs were required, which usually resulted in a confusing mess of connections that were hard to follow. Therefore, a universal system was needed that could be used on any controller design to aid in the understanding and tracking of the controller's inputs and outputs. A description of this system is given along with a detailed step by step process on how it was implemented on an Unmanned Air Vehicle (UAV).

DESCRIPTORS: (U) *COMPUTER PROGRAMS, *REMOTELY PILOTED VEHICLES, INTEGRATED SYSTEMS, CONTROL SYSTEMS, COMPUTATIONS, AIRCRAFT, EXPLOSIONS, TRACKING, THESES, UNMANNED, ENGINEERS, MODEMS.

AD-A322043/JAA

DEFENCE SCIENCE AND TECHNOLOGY ORGANIZATION
CANBERRA (AUSTRALIA)

(U) Data Link Technology for a Portable Unmanned Aerial Vehicle.

DESCRIPTIVE NOTE: Research report
NOV 1996 66 PAGES
PERSONAL AUTHORS: Kowalenko, Victor; Phipps, Jane; Cameron, Keith

UNCLASSIFIED REPORT

ABSTRACT: (U) This report examines data link requirements for a Portable Unmanned Aerial Vehicle. Crucial to the operation of such a data link is the development of suitable computer algorithms that are capable of significantly compressing and reconstructing image data in a timely manner for viewing at a remote station. As a consequence of the near real time requirement, we investigate recent advances in lossy data compression techniques concentrating on transform coding techniques involving the discrete cosine transform, fractals and wavelets. At present the discrete cosine transform is available on a microprocessor chip and can offer acceptable reconstructed images close to real time with compression ratios of up to 35:1, but other techniques promise even higher compression ratios and possibly a near real time capability in the not too distant future.

DESCRIPTORS: (U) *DATA LINKS, *REMOTELY PILOTED VEHICLES, FRACTALS, REQUIREMENTS, REAL TIME, OPTICAL IMAGES, DATA COMPRESSION, AUSTRALIA, MULTIPLEXING, DISCRETE FOURIER TRANSFORMS, COMMAND GUIDANCE, COMPRESSION RATIO, WAVELET TRANSFORMS.

IDENTIFIERS: (U) FOREIGN REPORTS, IMAGE COMPRESSION, DISCRETE COSINE TRANSFORMS

AD-A321482/JAA

RAND CORP
SANTA MONICA CA

(U) The Global Hawk Unmanned Aerial Vehicle Acquisition Process: a Summary of Phase I Experience,

1997 46 PAGES
PERSONAL AUTHORS: Sommer, Geoffrey; Smith, Giles K.; Birkler, John L.; Chiesa, James R.

UNCLASSIFIED REPORT

ABSTRACT: (U) There is a long history of efforts to improve the efficiency and effectiveness of the weapon acquisition process. The purpose of this case study is to understand how one such program, the High Altitude Endurance Unmanned Aerial Vehicle (HAE UAV), has benefited from certain changes in established acquisition procedures. It is hoped that conclusions can then be drawn regarding the suitability of these measures for the wider Department of Defense acquisition environment. The Defense Advanced Research Projects Agency (DARPA), in conjunction with the Defense Airborne Reconnaissance Office (DARO), is embarking on development of two Unmanned Air Vehicles (UAVs): Tier II and Tier III. UAV and Tactical Surveillance/Reconnaissance Programs have a history of failure due to inadequate integration of sensor, platform, and ground elements, together with unit costs far exceeding what the operator has been willing to pay. To overcome these historical problems, DARPA, with Congressional support, is undertaking an innovative acquisition program that is different from normal DoD acquisition efforts in several important ways: The approach gives flexibility to depart from acquisition specific law and related regulations. The program has been designated an Advanced Concept Technology Demonstration (ACTD), i.e., a program intended to demonstrate mature or maturing technologies to warfighters in an accelerated fashion.

DESCRIPTORS: (U) *DEPARTMENT OF DEFENSE, *MANAGEMENT PLANNING AND CONTROL, *ACQUISITION, *UNMANNED, *HIGH ALTITUDE, *MILITARY PROCUREMENT, *RECONNAISSANCE AIRCRAFT, WEAPONS, AERIAL RECONNAISSANCE, REQUIREMENTS, GROUND, DEMONSTRATIONS, PERFORMANCE.

IDENTIFIERS: (U) HAE UAV(HIGH ALTITUDE ENDURANCE UNMANNED AERIAL VEHICLE), ACTD(ADVANCED CONCEPT TECHNOLOGY DEMONSTRATION).

AD-A321302/JAA

OFFICE OF THE UNDER SECRETARY OF DEFENSE (ACQUISITION AND TECHNOLOGY) WASHINGTON DC

(U) UAV Annual Report, FY 1996.
6 NOV 1996 58 PAGES

UNCLASSIFIED REPORT

ABSTRACT: (U) Our second Unmanned Aerial Vehicle (UAV) annual report provides an overview of the Defense Department's UAV Program Activities for fiscal year (FY) 1996. The Defense Airborne Reconnaissance Office (DARO) is chartered to manage the Defense Airborne Reconnaissance Rrogram (DARP), which includes both tactical and endurance UAVs among its component program elements. During the past year, UAVs have seen major programmatic changes, have continued to demonstrate unique capabilities, and have experienced increasing acceptance by operational users. This report highlights their recent achievements, describes their acquisition plans and issues, and projects the DARO's UAV vision for the future.

DESCRIPTORS: (U) *AERIAL RECONNAISSANCE, *UNMANNED, *REMOTELY PILOTED VEHICLES, *RECONNAISSANCE AIRCRAFT, ACQUISITION, DEFENSE SYSTEMS, ENDURANCE(GENERAL), PLANNING, ACCEPTABILITY.

IDENTIFIERS: (U) *UNMANNED AERIAL VEHICLES.

AD-A321053/JAA

HUMAN FACTORS RESEARCH INST TNO SOESTERBERG (NETHERLANDS)

(U) Computer Generated Environment for Steering a Simulated Unmanned Aerial Vehicle (Computer gegenereerde omgeving voor het besturen van een gesimuleerd onbemand voertuig).

DESCRIPTIVE NOTE: Final report
1 OCT 1996 35 PAGES
PERSONAL AUTHORS: Erp, J. B. Van; Kappe, B.

UNCLASSIFIED REPORT

ABSTRACT: (U) Two important tasks in operating a maritime Unmanned Aerial Vehicle (MUAV) are controlling the airframe and its onboard camera. However, the visual information on which the human operator has to perform these tasks is of poor quality, due to the restricted capacity of the down link between MUAV and operator. This leads to performance degradation in search and tracking tasks and loss of situational awareness In previous experiments, it was shown that augmentation of the camera image by adding a Computer Generated Environment (CGE) improves performance in controlling the camera and enlarges situational awareness. The present experiment focuses on the possibilities of operating both the airframe and the onboard camera simultaneously, e.g. tracking a target ship while flying a circle around it. The experiment compared performance in four display type conditions: Two without augmentation (respectively north up and heading up), and two with augmentation (respectively a 2D CGE and a 3D CGE). The results show that the CGE is successful in supporting airframe control, without affecting tracking performance. No differences were found between the 2D and 3D CGE, and no differences were found between the north up and heading up displays without CGE. On the basis of these results, it is recommended to investigate the effects of integrating more information into the CGE (i.e. electronic maps), and to explore the possibilities of switching between 2D and 3D.

DESCRIPTORS: (U) *STEERING, *COMPUTER APPLICATIONS, *REMOTELY PILOTED VEHICLES, CONTROL, SIMULATION, ELECTRONICS, DEGRADATION, DATA TRANSMISSION SYSTEMS, CAPACITY(QUANTITY), PERFORMANCE(HUMAN), MOTION, TRACKING, TARGETS, DISPLAY SYSTEMS, IMAGES, UNMANNED, CAMERAS, AIRFRAMES, MAPS, VISION, OPERATORS (PERSONNEL).

AD-A320906/JAA

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT
NEUILLY-SUR-SEINE (FRANCE)

(U) Subsystem Integration for Tactical Missiles (SITM) and Design and Operation of Unmanned Air Vehicles (DOUAV) (L'Integration des sous-systemes dans les missiles tactiques et la conception et l'exploitation des vehicules sans pilote).

NOV 1996 345 PAGES

UNCLASSIFIED REPORT

ABSTRACT: (U) Both tactical missiles and Unmanned Air Vehicles (UAV) are important defense capabilities for NATO nations, and they will become more important in the future. The 21st century will be a turning point for tactical missiles and UAVs with regard to their affordability. Tactical missile suppliers are moving now toward efficiency which will greatly reduce the per unit costs. With dramatic improvements foreseen in multispectral sensors and secure, wideband data links, UAVs will come into their own as reconnaissance assets able to provide high quality, real time target imagery. The objective of these two meetings was to capture the current situation in these rapidly changing technical arenas. These specialists' meetings met their objective. Different parts of this conference proceedings should be valuable to anyone currently: (1) Considering the procurement and tactical application of UAVs and tactical missiles; (2) Designing or developing UAVs and tactical missiles; and, (3) Doing basic research in UAV. In the field of subsystem integration for tactical missiles, papers focused on successful examples of integrating advanced sensors, guidance control systems, and navigation systems. An additional session focused on methods for testing missiles, including lessons learned from Norway's testing of the Penguin Mk2. The meeting on UAVs focused on design issues, payloads and their associated technologies, and operational issues. Specific systems described included: The French Self Contained Early Warning System against Antiship Missiles; the Phoenix; Boeing's Heliwing; the Crecelle, and the U.S. Navy's tilt rotor UAV demonstrator.

DESCRIPTORS: (U) *GUIDED MISSILES, *UNMANNED, *TACTICAL WEAPONS, *STRIKE WARFARE, *TACTICAL AIRCRAFT, *STANDOFF MISSILES, NATO, SYMPOSIA, CONTROL SYSTEMS, LESSONS LEARNED, DETECTORS.

AD-A320663/JAA

PHILLIPS LAB
HANSCOM AFB MA

(U) Global Weather Awareness,

11 MAY 1996 15 PAGES
PERSONAL AUTHORS: Mcclatchey, Robert A.; Greenwood, Darryl P.

UNCLASSIFIED REPORT

ABSTRACT: (U) The meteorological needs of the military include but go well beyond the civilian scope because of a requirement to operate globally - anywhere and anytime - and over very specific sites, often in poor visibility conditions. To complicate matters, areas of interest to the military are often access-denied, thus emphasizing remote sensing (satellite-, aircraft-, and ground-based). The Air Force, by the very nature of its mission, needs to know weather information in areas where such information is the most difficult to obtain. Despite the added difficulties, the need for global three-dimensional observations is common to both the military and civilian worlds of meteorology; thus the defense and Commerce Departments have started collaborating to converge the Air Force's DMSP (Defense Meteorological Satellite Program) and NOAA's polar satellites into one satellite system for the future. The first NPOESS satellite is slated for launch in 2008, but many technologies needed to meet the baseline requirements are not yet here (example: active sensing technology, using lasers to provide better information on winds and aerosols, and microwave sources to provide better information on dense aerosols, including clouds).

DESCRIPTORS: (U) *MILITARY REQUIREMENTS, *WEATHER FORECASTING, GLOBAL, METEOROLOGICAL DATA, METEOROLOGICAL SATELLITES, SURVEYS, UNMANNED, METEOROLOGICAL INSTRUMENTS, TIMELINESS, REMOTELY PILOTED VEHICLES, AIR FORCE OPERATIONS, DECISION SUPPORT SYSTEMS.

IDENTIFIERS: (U) GLOBAL 3-DIMENSIONAL OBSERVATIONS, PE62601F, WUPL6670GR15

AD-A319965/JAA

AEROSPACE CORP
LOS ANGELES CA

(U) Interceptor Concepts For The U.S. UAV BPI Program,

SEP 1996 12 PAGES
PERSONAL AUTHORS: Brown, Steve; Zondervan, Kevin L.; Barrera, Mark; Urbano, Reynaldo; Svorec, Ray

UNCLASSIFIED REPORT

ABSTRACT: (U) The Ballistic Missile Defense Organization (BMDO) is managing the U.S. Unmanned Aerial Vehicle (UAV) boost phase intercept (BPI) program. The program's goal is to investigate the potential of UAV-based interceptors to provide a boost-phase defensive tier against theater ballistic missiles. A technology assessment and risk mitigation effort is underway to determine the requirements of a UAV BPI system. The advanced systems directorate, Space and Missile Systems Center, Air Force Material Command (AFMC/SMC/ADE) has been selected to lead the interceptor integrated product team (IPT). The interceptor IPT's efforts during its first year have been focused on surfacing attractive interceptor conceptual designs and selecting a preliminary design. This paper presents the requirements and rationale leading to the preliminary interceptor design. The history of the concept of airborne interceptors for boost-phase defense is briefly reviewed, including how a consensus emerged for the current UAV-based approach. Top-level interceptor requirements are then derived and several concepts are proposed for meeting them. The pros and cons of the alternative interceptor concepts are examined, leading to a single concept. A preliminary interceptor design is then presented for this concept.

DESCRIPTORS: (U) *ANTIMISSILE DEFENSE SYSTEMS, *INTERCEPTORS, *REMOTELY PILOTED VEHICLES, GUIDED MISSILES, MILITARY REQUIREMENTS, THEATER LEVEL OPERATIONS, INTEGRATED SYSTEMS, AIRCRAFT, RISK, DEFENSE SYSTEMS, BOOST PHASE, AIRBORNE, INTERCEPTION, TEAMS(PERSONNEL), SURFACES, UNMANNED, AIR FORCE FACILITIES.

AD-A315813/JAA

NEW MEXICO STATE UNIV
LAS CRUCES

(U) Unmanned Aerial Vehicle Dropsondes with Global Positioning System Windfinding.

DESCRIPTIVE NOTE: Final report
MAY 1996 37 PAGES
PERSONAL AUTHORS: Greenling, T.; Luces, S. A.; Thomas, J.

UNCLASSIFIED REPORT

ABSTRACT: (U) Detailed, quantitative, atmospheric data are essential for accurate analyses and forecasting of mesoscale phenomena for military and civilian applications. Over remote areas, environmental satellites provide qualitative and broadscale quantitative information more suitable for synoptic scale analyses. Because satellite instruments for measuring atmospheric variables have relatively large footprints and vertical resolutions, airborne systems remain the only reliable source of detailed, quantitative, accurate data for remote mesoscale areas, especially 500 by 500 km or smaller. Within remote or hazardous regions, use of manned aircraft for gathering atmospheric data may not be feasible because of the high risk to personnel and expensive equipment. Unmanned aerial vehicles can carry small sensors and dropsondes into these areas, at no risk to personnel and at a very low cost. The Battlefield Environment Directorate of the Army Research Laboratory led the development of a dropsonde with Global Positioning System (GPS) windfinding capability, assisted by the Physical Sciences Laboratory of New Mexico State University. This report briefly discusses the dropsondes and presents the results of the flight test at the conclusion of phase 1. Phase 1 investigated current off-the-shelf capability (as of late 1994) with a modification to obtain wind profiles via GPS techniques. Plans include a phase 2 that will seek to produce proof-of-concept prototype dropsondes and dispenser.

DESCRIPTORS: (U) *GLOBAL POSITIONING SYSTEM, *REMOTELY PILOTED VEHICLES, FLIGHT TESTING, SOURCES, ARMY RESEARCH, DETECTORS, HIGH RATE, AIRCRAFT, RISK, HAZARDS, LOW COSTS, BATTLEFIELDS, AIRBORNE, WIND, OFF THE SHELF EQUIPMENT, ACCURACY, PROTOTYPES, METEOROLOGICAL DATA, RELIABILITY, PROFILES, UNMANNED, ARTIFICIAL SATELLITES, MILITARY APPLICATIONS.

AD-A315466/JAA

LOYOLA COLL
BALTIMORE MD

(U) Submersibles and Marine Technologies in Russia's Far East and Siberia.

DESCRIPTIVE NOTE: Final report
AUG 1996 159 PAGES
PERSONAL AUTHORS: Mooney, Brad; Ali, Hassan B.; Blidberg, Richard; Dehaemer, Michael; Gentry, Larry

UNCLASSIFIED REPORT

ABSTRACT: (U) This report is a review of research submersible vehicles and other marine technologies in Siberia and the Russian Far East. It complements a 1994 WTEC report covering submersible technologies in Ukraine and European Russia. The panel found that two institutions in Vladivostok have extensive developments and experience in operating Remotely Operated Vehicles (ROVS) and Autonomous Underwater Vehicles (AUVs). In particular, two prototype AUVs developed by the institute for marine technology problems (IMTP) are rated at 6000 meters operating depth, one of which has logged 160 working dive missions greater than 4000 meters. The WTEC panelists concluded that IMTP had more AUV operating experience than all U.S. programs combined. The panel also visited several centers of excellence in the Novosibirsk area, including the Institute of Thermodynamics and Applied Mechanics, which is world- class facility for research on aerodynamics, including eight wind tunnels achieving air speeds up to mach 25.

DESCRIPTORS: (U) *RESEARCH FACILITIES, *RUSSIA, *MARINE ENGINEERING, *SUBMERSIBLES, *SIBERIA, *FAR EAST, COMPUTER PROGRAMS, EUROPE, UNDERWATER VEHICLES, ECONOMICS, THERMODYNAMICS, BIOCHEMISTRY, ENERGY, PROTOTYPES, PHYSICS, TEST VEHICLES, AIRSPEED, SELF OPERATION, MARINE BIOLOGY, AUTONOMOUS NAVIGATION, BUDGETS, REMOTELY PILOTED VEHICLES, WIND TUNNELS, INTERNATIONAL RELATIONS, AERODYNAMICS, APPLIED MECHANICS, ORGANIC CHEMISTRY, UKRAINE.

AD-A314057/JAA

NAVAL AIR WARFARE CENTER
AIRCRAFT DIV
PATUXENT RIVER MD

(U) Simulation Support of a 17.5% Scale F/A-18E/F Remotely Piloted Vehicle.

DESCRIPTIVE NOTE: Professional paper
30 MAY 1996 10 PAGES
PERSONAL AUTHORS: Fitzgerald, Timothy R.; Gingras, David R.

UNCLASSIFIED REPORT

ABSTRACT: (U) As defense budgets continue to shrink, cost-effective methods for the accurate and timely acquisition of aerodynamic data must be developed. Traditionally, wind tunnels have fulfilled this role at both the conceptual and developmental stages, as well as throughout the service life of an aircraft. However, although wind tunnels are a trusted and valuable data source that provide consistent repeatable data upon which to construct aerodynamic models, they also have inherent limitations such as blockage effects, w11 and sting interference, and flow variations. Because of these constraints and due to the elevated angles-of-attack and sideslip that modern fighter aircraft are capable of, wind tunnels can be limited in their ability to cover an entire flight envelope.

DESCRIPTORS: (U) *ATTACK AIRCRAFT, *JET FIGHTERS, *REMOTELY PILOTED VEHICLES, SIMULATION, FIGHTER AIRCRAFT, SOURCES, METHODOLOGY, DEPARTMENT OF DEFENSE, AIRCRAFT, ACQUISITION, COST EFFECTIVENESS, LIFE EXPECTANCY(SERVICE LIFE), ACCURACY, CONSISTENCY, VARIATIONS, FLOW RATE, INTERFERENCE, SIDESLIP, STING MOUNTS, BLOCKING, FLIGHT ENVELOPE, TIMELINESS, REPRODUCIBILITY, MILITARY BUDGETS, WIND TUNNELS, AERODYNAMICS.

IDENTIFIERS: (U) F/A-18E/F AIRCRAFT.

AD-A312932/JAA

NAVAL POSTGRADUATE SCHOOL
MONTEREY CA

(U) A Methodology for Evaluating the Capability of the Bradley 25mm Cannon to Engage and Defeat Pioneer Class Unmanned Aerial Vehicles.

DESCRIPTIVE NOTE: Master's thesis,
JUN 1996 109 PAGES
PERSONAL AUTHORS: Wiley, Danny A.

UNCLASSIFIED REPORT

ABSTRACT: (U) Unmanned Aerial Vehicles (UAVs) represent a serious threat to forward deployed forces of the United States Army. The defense against such threats is currently provided primarily by the Bradley Stinger Fighting Vehicle (BSFV). The problem addressed is how to evaluate the effectiveness of the BSFV against a UAV. This thesis develops a computer simulation methodology for modeling the capability of a gun system to engage a UAV. Specifically, a review is made of the BSFV, BSFV 25mm ammunition, and UAVs. These reviews formed the basis for a computer simulation, coded in Common Lisp Object System (CLOS) modeling the characteristics of three objects: A projectile, a launcher and a UAV. Although assumptions were made to simplify the model, simulation runs demonstrated that the rate of fire and aiming system used for launching projectiles resulted in one or more hits in 125 out of 154 engagement sequences. These engagement sequences were against a UAV flying at constant speed and altitude in crossing and inbound/outbound flight profiles. While all data used in this simulation were unclassified report, the methodology presented could be used for further classified study, potentially producing a lower cost means for determining the effectiveness of air defense weapons against UAV threats.

DESCRIPTORS: (U) *COMPUTERIZED SIMULATION, *ANTIAIRCRAFT GUNS, *FORWARD AREA AIR DEFENSE SYSTEMS, WEAPONS, MILITARY FORCES(UNITED STATES), SIMULATION, METHODOLOGY, DEPLOYMENT, LOW COSTS, PROJECTILES, THESES, UNMANNED, LAUNCHING, COMBAT VEHICLES, AIMING, ARMY, REMOTELY PILOTED VEHICLES, FLIGHT SPEEDS, FIRING RATE.

IDENTIFIERS: (U) UAV(UNMANNED AERIAL VEHICLES), BSFV(BRADLEY STINGER FIGHTING VEHICLE), 25-MM GUNS.

AD-A311521/JAA

NAVAL POSTGRADUATE SCHOOL
MONTEREY CA

(U) The HAE UAV and Dynamic Retasking by Tactical Commanders.

DESCRIPTIVE NOTE: Master's thesis,
JUN 1996 110 PAGES
PERSONAL AUTHORS: Waller, Howard T.

UNCLASSIFIED REPORT

ABSTRACT: (U) Advancing technology and the changing nature and tempo of modern warfare has created many challenges. Desert storm reiterated the need for Near-Real Time (NRT) imagery of the battlefield. History shows that Unmanned Aerial Vehicles (UAV) have the capability to meet some of these challenges. The Defense Airborne Reconnaissance Office (DARO) is directing a program to develop a family of UAVs that will meet the future NRT imagery needs of operational commanders. The High Altitude Endurance (HAE) UAV is part of this family of UAVs that will serve to provide sustained, broad area coverage for those commanders with time critical needs. The thrust of this thesis is to define a process by which the time-critical Reconnaissance Surveillance and Target Acquisition (RSTA) imagery needs of the tactical commander on the battlefield can be met through effective dynamic retasking of the HAE UAV. This thesis examines HAE UAV capabilities, the intelligence cycle, and collection management procedures. Prohibitors of timely intelligence are highlighted. A process is described through which the HAE UAV may be dynamically retasked to meet the ground force commander's real-time collection requirements. The appropriateness of the HAE UAV to be used to satisfy the ground force commander's dynamic requirements is discussed.

DESCRIPTORS: (U) *AERIAL RECONNAISSANCE, *BATTLEFIELDS, *DATA ACQUISITION, *USER NEEDS, *DRONES, *MILITARY COMMANDERS, *TACTICAL INTELLIGENCE, MILITARY OPERATIONS, IRAQ, KUWAIT, MILITARY REQUIREMENTS, LESSONS LEARNED, DEFENSE SYSTEMS, MANAGEMENT, REAL TIME, TARGET ACQUISITION, THESES, CYCLES, TIME, ENDURANCE (GENERAL), UNMANNED, HIGH ALTITUDE, TACTICAL WARFARE, AREA COVERAGE, COLLECTING METHODS, RECONNAISSANCE AIRCRAFT.

AD-A310299/JAA

ARMY COMMAND AND GENERAL STAFF COLL
FORT LEAVENWORTH KS
SCHOOL OF ADVANCED MIL ITARY STUDIES

(U) Human Intelligence: Long-Range Surveillance for Force XXI

DESCRIPTIVE NOTE: Monograph,
18 JAN 1996 57 PAGES
PERSONAL AUTHORS: Cochran, Lewis C.

UNCLASSIFIED REPORT

ABSTRACT: (U) This monograph examines the utility of long-range surveillance human intelligence as part of a larger intelligence gathering system. The paper proposes that even with the acquisition of high-technology intelligence gathering systems, such as Unmanned Aerial Vehicles (UAV) and the Joint Surveillance Target Attack Radar System (JSTARS), Long-Range Surveillance Units (LRSU) are still an essential part of the system. LRSU do have significant problems associated with their employment currently. The most significant problems are communications equipment, doctrine and organization. These elements limit LRSU effectiveness now and in the future within the framework of force XXI operations. This monograph contains seven sections: introduction, history of LRSU, the Revolution in Military Affairs (RMA), LRSU doctrine, force XXI operations, LRSU for force XXI, and conclusion. The history section sheds light on the origins of the LRSU mission through World War II, Korea, Vietnam and the 9th Infantry Division test unit of the early 1980's. The section on the RMA examines the problems with LRSU equipment, specifically communications, and how the RMA may affect It. It also examines the future viability of the UAV and JSTARS as examples of advanced technology made possible by the RMA. The fourth section, LRSU doctrine, reveals its origins and the revision of the doctrine in 1992. It establishes the base line for future challenges for LRSU within force XXI. The force XXI section explains the characteristics of those operations and how LRSU are and are not prepared to support them.

DESCRIPTORS: (U) *MILITARY INTELLIGENCE, *RADAR RECONNAISSANCE, AERIAL RECONNAISSANCE, MILITARY HISTORY, BATTALION LEVEL ORGANIZATIONS, MILITARY DOCTRINE, PERFORMANCE(HUMAN), COMBAT SURVEILLANCE, LONG RANGE(DISTANCE), JOINT MILITARY ACTIVITIES, SEARCH RADAR.

AD-A310111/JAA

ADVISORY GROUP FOR AEROSPACE
RESEARCH AND DEVELOPMENT
NEUILLY-SUR-SEINE (FRANCE)

(U) Integrated Vehicle Management Systems (Systemes de gestion de vecteur integre).
APR 1996 139 PAGES

UNCLASSIFIED REPORT

ABSTRACT: (U) Major trends in technology, weapon system performance goals and affordability for aerospace systems are occurring simultaneously. For avionic systems this performance and affordability can be achieved by functional and physical integration. 'Functionally' integrated subsystems to achieve higher performance has been greatly aided by advances in computer technology. The desire to minimize costs for these systems has been accomplished through a 'physical' integration concept based upon common modules tied through a high speed backplane. The concept, called integrated avionics, has been used on new aircraft such as the U.S. Air Force F-22 Fighter and the Boeing 777 Commercial Transport. Vehicle management systems provide the management of crucial flight functions and systems for advanced aerospace vehicles. These systems must have high integrity, safety, and overall fault tolerance. Low cost modular avionics are unproven for such fault tolerant systems. This becomes a key issue for investigation. This report deals with the key problems in fault tolerance for modular computer based systems. New techniques, only recently applied, provide exciting possibilities to reduce avionics costs and maintain high integrity and safety. These techniques and more are discussed in this report sponsored by the mission systems panel of the AGARD.

DESCRIPTORS: (U) *AVIONICS, *INTEGRATED SYSTEMS, *WEAPON SYSTEMS, *AEROSPACE SYSTEMS, GUIDED MISSILES, NATO, MANAGEMENT, FLIGHT CONTROL SYSTEMS, LOW COSTS, COMPUTERS, COSTS, PROPULSION SYSTEMS, HELICOPTERS, INTEGRATION, WEAPON SYSTEM EFFECTIVENESS, MISSIONS, AEROSPACE CRAFT, VEHICLES, FAULT TOLERANCE, HIGH RELIABILITY.

IDENTIFIERS: (U) UAV(UNMANNED AERIAL VEHICLES).

AD-A310003/JAA

NATIONAL AIR INTELLIGENCE CENTER
WRIGHT-PATTERSON AFB OH

(U) Applications of GPS in Airborne Electronic Countermeasure Reconnaissance,

APR 1996 10 PAGES
PERSONAL AUTHORS: Zhigang, Zhang

UNCLASSIFIED REPORT

ABSTRACT: (U) When implementing electronic counter reconnaissance or other electronic countermeasure missions on moving platforms, operating personnel working on the platforms must grasp in real time the exact position of the platform itself. In command posts or control centers, there is a need to understand, in real time, the direction of platform movements. When implementing the positioning of emitting sources, precise platform locations are even more indispensable. In the past, on aircraft, reliance was put on inertial navigation systems and aviation instruments to provide data and, after processing, precise positions. The limitations associated with making use of this type of method are relatively large. Precisions are not high. Real time characteristics are relatively bad. Opting for the use of digital transmission navigation display systems based on global satellite navigation systems avoids the shortcomings discussed above. Moreover, it is possible to conveniently generalize application to various types of mobile platforms.

DESCRIPTORS: (U) *AERIAL RECONNAISSANCE, *GLOBAL POSITIONING SYSTEM, *ELECTRONIC COUNTERMEASURES, POSITION(LOCATION), REAL TIME, MOTION, CONTROL CENTERS, AERONAUTICS, PLATFORMS, MOBILE, MISSIONS, PRECISION, NAVIGATION SATELLITES, ARTIFICIAL SATELLITES, INSTRUMENTATION, TRANSLATIONS, CHINA, CHINESE LANGUAGE.

AD-A307884/JAA

NAVAL AIR WARFARE CENTER
AIRCRAFT DIV PATUXENT
RIVER MD

(U) Simulation Support of a 17.5 Percent Scale F/A-18E/F Remotely Piloted Vehicle,

27 FEB 1996 2 PAGES
PERSONAL AUTHORS: Fitzgerald, Timothy R.

UNCLASSIFIED REPORT

ABSTRACT: (U) As defense budgets continue to shrink, cost-effective methods for the accurate and timely acquisition of aerodynamic data must be developed. Traditionally, wind tunnels have fulfilled this role at both the conceptual and developmental stages, as well as, throughout the service life of an aircraft. However, although wind tunnels are a trusted and valuable data source that provide consistent, repeatable data upon which to construct aerodynamic models, they also have inherent limitations such as blockage effects, wall and sting interference, and flow variations. Because of these constraints and due to the elevated angles-of-attack and sideslip that modern fighter aircraft are capable of, wind tunnels can be limited in their ability to cover an entire flight envelope. Another problem with the construction of aerodynamic models using wind tunnel data is the discontinuities that arise from the fundamental requirement for multiple -- and usually dissimilar -- data sources to construct a full-envelope model (rotary balance data combined with low-speed forced oscillation data; low-speed static data appended with supersonic data; and so on). A final problem that plagues wind tunnel testing.

DESCRIPTORS: (U) *ATTACK AIRCRAFT, *JET FIGHTERS, *REMOTELY PILOTED VEHICLES, SOURCES, METHODOLOGY, EXPERIMENTAL DATA, ACQUISITION, COST EFFECTIVENESS, LIFE EXPECTANCY(SERVICE LIFE), FACILITIES, ACCURACY, ANGLE OF ATTACK, VARIATIONS, LOW VELOCITY, FLOW RATE, CONSTRUCTION, WIND TUNNEL TESTS, BUDGETS, TIMELINESS, AIRCRAFT MODELS, SUPERSONIC CHARACTERISTICS, OSCILLATION, STATICS, ROTATION, FLIGHT SIMULATION, REPRODUCIBILITY, AERODYNAMICS, PLAGUES.

AD-A307450/JAA

NAVAL WAR COLL
NEWPORT RI

(U) Joint Doctrine and UAV Employment.

DESCRIPTIVE NOTE: Final report
12 FEB 1996 20 PAGES
PERSONAL AUTHORS: Lukaszewicz, Thomas B.

UNCLASSIFIED REPORT

ABSTRACT: (U) Current joint doctrine on Unmanned Aerial Vehicle (UAV) employment, though extensive, does not provide sufficient clarity and scope to fully exploit emerging UAV capabilities. Joint doctrine does not sufficiently address the role of integrating component commanders UAV assets into JTF operations or define adequate procedures for prioritizing UAV missions to meet JFC objectives. doctrine must suggest procedures and an organizational structure to balance intelligence collection objectives and operational requirements for RSTA as the number and capabilities of UAVs available to the JFC increase, the amount and timeliness of RSTA information available to the JFC will expand dramatically. current JTF/JFACC organizational structures and procedures are insufficient to plan, prioritize and exploit this increased data flow. Joint doctrine must be updated to reflect new UAV systems, define service/JTF UAV responsibilities, and suggest organizational and procedural structures that can manage the increased volume and timeliness of UAV derived RSTA information.

DESCRIPTORS: (U) *MILITARY DOCTRINE, *REMOTELY PILOTED VEHICLES, AERIAL RECONNAISSANCE, DATA PROCESSING, REQUIREMENTS, ORGANIZATIONS, AIRCRAFT, JOINT MILITARY ACTIVITIES, UNMANNED, BALANCE, DATA ACQUISITION, FLOW, SURVEILLANCE.

AD-A307294JAA

NAVAL POSTGRADUATE SCHOOL
MONTEREY CA

(U) Computer Simulation of an Unmanned Aerial Vehicle Electric Propulsion System.

DESCRIPTIVE NOTE: Master's thesis
MAR 1996 122 PAGES
PERSONAL AUTHORS: Yourkoski, Joel

UNCLASSIFIED REPORT

ABSTRACT: (U) There has been a substantial increase in the use of electric propulsion systems in Unmannned Aerial Vehicles (UAVs). However, this area of engineering has lacked the benefits of a dynamic model that could be used to optimize the design, configurations and flight profiles. The Naval Research Laboratory (NRL) has accurate models for the aerodynamics associated with UAVs. Therefore the proposed electric propulsion model would use the torque and RPM requirements generated by the aerodynamic model and provide an accurate representation of the desired UAV electric propulsion system. This thesis reports on the development of such a model. The model is adaptive in the sense that motor and battery parameters can be altered by the user to reflect systems currently in use or those considered for future systems. Not only will the simulation model accurately reflect the operating conditions of the motor and battery during the mission, but different flight profiles with the same configuration can be evaluated in terms of efficiency based on the percent battery capacity used (PBCU) at the end of the mission. This electric propulsion simulator is part of a larger NRL project intended to design and deliver UAVs to the Naval Service over the next few years.

DESCRIPTORS: (U) *COMPUTERIZED SIMULATION, *SYSTEMS ENGINEERING, *UNMANNED, *AIRCRAFT MODELS, *ELECTRIC PROPULSION, COMPUTER PROGRAMS, AERODYNAMIC CONFIGURATIONS, SIMULATORS, OPTIMIZATION, MODELS, DYNAMICS, ACCURACY, EFFICIENCY, THESES, ENGINEERING, MISSIONS, USER NEEDS, NAVAL RESEARCH, NAVAL RESEARCH LABORATORIES, FLIGHT PATHS, MOTORS, TORQUE, ELECTRIC BATTERIES.

IDENTIFIERS: (U) UAV (UNMANNED AERIAL VEHICLES), PBCU(PERCENT BATTERY CAPACITY USED).

AD-A305682/JAA

AIR UNIV MAXWELL AFB AL
SCHOOL OF ADVANCED
AIRPOWER STUDIES

(U) Special Operations Forces and Unmanned Aerial Vehicles. Sooner or Later?

FEB 1996 46 PAGES
PERSONAL Authors: Howard, Stephen P.

UNCLASSIFIED REPORT

ABSTRACT: (U) This study analyzes whether Special Operations Forces (SOF) should use Unmanned Aerial Vehicles (UAV) to support intelligence, surveillance, reconnaissance, communications, and resupply capability deficiencies. The author's objective is to review the missions and requirements of the United States Special Operations Command, examine current and future Unmanned Aerial Vehicle technologies, and analyze whether unmanned aircraft technologies are mature enough to meet the demanding special operations mission. The result of the analysis is that Unmanned Aerial Vehicles have tremendous potential. But, due to the technological limitations and a lack of systems maturity, Unmanned Aerial Vehicles lack the range, reliability, datalink capability, and size to meet SOF needs at this time. However, in the future, UAVs should be able to fulfill several SOF capability deficiencies.

DESCRIPTORS: (U) *SPECIAL FORCES, *REMOTELY PILOTED VEHICLES, INTELLIGENCE, AIRCRAFT, RELIABILITY, LIMITATIONS, MISSIONS, DEFICIENCIES, UNMANNED, DATA LINKS, RECONNAISSANCE, REPLENISHMENT.

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